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REPORT TO THE GOVERNMENT OF CHILE

THE VOLCANIC ASH SOILS OF CHILE

WITH PARTICULAR REFERENCE TO TRUMAO SOILS AND ÑADI SOILS

by

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TABLE OF CONTENTS

I N T R O D U C T I O N

A. The Volcanic Landforms of Chile and Similar Landscapes of the Circum-Pacific Region

The Pacific Ocean is bordered by volcanoes from Mt. Erebus in New Zealand Antarctica, northward through New Zealand, New Guinea, the Phillipine archipielago to Japan and the Kamchatka peninsula; thence in a returning arc through Alaska and the Rocky Mountains, to the isthmus of Central America, and on down the Andean chain to the volcanic peaks of Antarctica Chilena. Moreover, the great majority of the islands and island chains dotted across the Ocean itself are wholly or partly of volcanic origin. It is thus not surprising that the study of volcanic landforms and of volcanic ash soils should have become the particular concern of geologists and pedologists in the circum-Pacific territories, (fig. 1).

Landforms of volcanic origin include not only the volcanoes themselves, but also the landscapes produced by the various flow rocks originating from the volcanoes, and many alluvial and colluvial landforms produced as an indirect result of volcanic activity; together with the various layers of volcanic ash and their own derived alluvial and colluvial products which mantle the older landforms. In some parts of Chile, as in parts of Japan and New Zealand, up to 90% of the landscape may consist of landforms of volcanic origin, mantled in volcanic ash or derived materials.

The materials emitted from volcanoes consist of gases, liquids and solids (see frontispiece). The liquid componant includes lava, which is a mixture of minerals, chiefly silicates, in a state of fusion, or of solution the one in the other. It varies widely in mineral, and hence in chemical composition, and so forms on solidification, a considerable variety of rocks. The lava exists within the lithosphere (below the crust of the earth) as a magma, and the places of ejection, are points of weakness in the earth's crust. The magma, the hot, fluid rock of the earth's interior, is probably not a continuous system, but is produced many miles below the earth's crust in places where there is some local diminution of the general enormous pressure exerted by the weight of the overlying rocks. The magmas of the earth are a concept: they have never been seen and never been sampled, and they can be judged only by the nature of their extruded rocks, - the lavas, and by the finely divided ejecta, - the volcanic ashes.

Basic lavas are poor in silica and rich in iron and magnesia, and on cooling give rise to basalt and related rocks; at the other extreme, acid lavas are very rich in silica and give rise to acidic rocks such as rhyolite and dacite. Lavas of intermediate composition give rise to intermediate types of volcanic rock such as andesite and trachyte. Magma may arrive at the escape vent in various conditions, in extremely fluid form or more viscid, highly gaseous and ebullient or relatively quiescent; and may encounter resistance in the shape of a previously formed plug in the neck of the volcano, or a hard rock carapace. It is these conditions in the vent that largely determine whether the eruption is of an explosive nature, or a mere, relatively gentle, outflowing of liquid lava. In extreme cases, pressure builds up until the whole mountain may explode and a rain of chunks of rocks mixed with fragments of cooling magma falls over a wide area. Volcanic ash is essentially the cold, explosively-comminuted fine fragments of the formerly liquid magma, although this material is commonly mixed with actual rock fragments shattered from the original framework of the volcano.

Volcanic ash is produced in the greatest quantities by the more explosive type of eruption, and hence is associated more with the rise of viscid, gas-charged acid magma than with liquid basic magma. The latter type of magma may also be highly gaseous, but the eruptive products are more usually scoriaceous lava and only a relatively small amount of fine (but heavy) particles are thrown high into the air, to fall back to earth as basaltic sand; heavy sand deposits of this type usually covers a relatively restricted area around the vent of origin. The more viscid magmas usually become inflated owing to the liberation of gases throughout the body of the materials, in the actual conduit through which it is rising towards the surface. Owing to the relief of pressure as the surface is approached, the gases expand and provide power for the explosive ejection of the lava that follows. Some lavas are converted into foam, which solidifies into pumice. Pumice is thus usually a highly siliceous type of volcanic glass, and may be ejected as large lumps, or small pellets (lapillae), or as a powder consisting mainly of tubular shreds of glass and isolated minute crystals that separated out from the magma during the rapid cooling process. This very fine ash may rise to great heights in the atmosphere, where it may cause cloud condensation and so return, in part, to the surface of the earth as a rain of fine, light gray volcanic mud. Magmas of intermediate composition also give rise to a large quantity of fine volcanic ash, usually less obviously pumiceous, and with rather larger mineral crystals since some of these began to crystalise out while the lava was still in the neck of the volcano. During the explosive ejection of this cooling material, many of the mineral crystals are shattered. Although whole crystals, and shattered fragments of whole mineral crystals, are always present in volcanic ash materials, the dominant material is normally fused volcanic glass, formed chiefly of silica and alumina, with iron as an appreciable constituent only where more basic magmas are involved.

Many volcanic landforms are deeply mantled in volcanic ash. These deposits are commonly stratified, showing alternate banding of the materials representing successive deposits from continuing eruptions. Particularly in regions where there are several volcanic vents in close proximity, the ash stratigraphic column may differ very widely from place to place, depending upon the different sources of the ash, and the different kinds of parent magmas. In Chile, where volcanoes are often aligned as a chain along the face of the Andes, only a few tens of kilometers apart, it is common to find interstratified ash beds with rhyolitic pumice alternating with andesitic or basaltic sand. In general, the ash layers belong to one of two types: those derived from paroxysmal volcanic activity (i.e., a single violent eruption of short duration), and those derived from volcanic activity of an intermittent nature. In the latter case the ash materials accumulate slowly over a longer interval of time, often only a few millimeters during successive eruptions, to form a relatively homogeneous layer of ash which can conveniently be regarded as a single discrete ash layer or bed. On the other hand, ash materials accumulating as a result of a paroxysmal eruption show gradation from coarse to fine materials, sometimes repeated many times, and so may be recognised as discrete shower horizons or strata (Taylor, 1933).

In volcanic regions, volcanic ash usually forms the chief componant of the superficial cover of the landscape: the landforms themselves are built up by a wide variety of volcanic phenomena, and may extend far across lowlands in the vicinity of the volcanoes. Intense volcanic activity is often accompanied by heavy rain (sometimes strongly acidified by solution of volcanic gases) which immediately resorts the finer ejecta on the hill slopes and floods the valleys with volcanic alluvium; the overloaded streams may spread out over the lowlands forming a whole new series of terrace levels, plains and deltas. Pumiceous alluvium in particular, may be redeposited in many strange forms, for the pieces are often very large and float well until suddenly the amount of water for floatation becomes inadequate, leaving steeply convex levées, or fan deposits with a micro-relief resembling frozen waves.

In situations where the vicinity of the volcano was initially snow-covered or frozen, the abrupt discharge of hot materials produces a great volume of steam, which often provides a lubricant for the lava or hot ash near the vent, and consequently swift-flowing streams of assorted fragments sweep down on the lowlands to become deposited as tuff, breccia or even simple mud-flows. Sometimes a thin, liquid lave stream crosses the bed of rivers containing water, turning the water to steam. This often causes a great acceleration in the pace of the lava, since it can now flow rapidly onward on a cushion of steam, leaving behind a chain of lava blisters and scoria mounds where the steam has forced a way upwards through the lava. Or, if the original magma is intensely charged with gas, the eruption may produce lava which is closely allied to a gaseous emulsion, and in this form it is capable of sweeping down from the vent as a fiery cloud (nuée ardente) with incredible speed. Other types of eruption may produce incandescent sand flows. Many volcanic landforms are the result of secondary effects, such as the blocking of a mountain valley by a lava barrier behind which a new lake slowly forms, eventually breaking through the barrier to discharge a wave of volcanic debris over the adjacent lowlands. Of more local importance is the eruption which breaks through in an old crater lake, throwing the muddy sediments of the lake over the landscape of the immediate vicinity.

Examples of practically all these volcanic landforms can be found in Chile (where they are still occasionally confused with glacial landforms), paralleling those known and described from Japan, New Zealand, Alaska, and other countries of the circum-Pacific area. Since many of the more active

Chilean volcanoes occur in the colder latitudes, it is not surprising that mudflows, tuff-flows and breccia-flows, aided and accelerated by the melting of snow and ice, are a common feature of the lowland landscape. They are important in the study of volcanic ash soils because they contain volcanic minerals and a measure of volcanic glass in their composition, consequently their soils often show properties allied to those of the soils formed wholly from volcanic ash.

One of the essential characteristics of volcanic ash soils is that they are formed from materials very rich in volcanic glass. As this material weathers, the transformation of alumina and silica to amorphous gels, and side reactions with amorphous organic compounds, donate to these soils a measure of individuality which sets them somewhat apart from the rest of the soils of the World. It is not so much their appearance, but their distinct chemical and physical properties that forces, the farmers, in particular, to call for their recognition as a discrete entity in the soil assemblage of the landscape. However, this does not apply in all environments. Since most of the particular properties of these soils are dependant upon a certain measure of soil weathering, there is no call for recognition of a special group of volcanic ash soils in arid or semi-arid regions where there is inadequate moisture to promote rapid weathering; nor in the very cold regions, where weathering is likewise delayed. Thus volcanic ash soils emerge as an entity of significance to the farming community, in environments where there adequate moisture and sufficiently high mean annual temperatures to promote a certain degree of weathering. Another special, although not so exclusive (since it is shared also with alluvial and some wind-blown deposits), feature is that volcanic ash soil parent materials are usually deposited as unconsolidated layers, and the weathering of freshly deposited materials takes place in depth, simultaneously affecting the whole thickness of a layer, so that the same weathering products are being produced almost simultaneously at a myriad of foci, over a fixed depth, and from the surface downwards. This feature imparts to the soil a measure of uniformity over a specific depth, and makes possible the complete dominance of certain weathering products. This is very different from the situation in soils that are being formed by the progressive decay of materials first produced in a narrow zone near the solid rock face. It is in this aspect that the soils derived from loose and porous ash beds differs most markedly from soils derived from consolidated volcanic beds, such as tuffs, breccias, or hardened mudflows, which otherwise may have much the same volcanic composition as the unconsolidated ash. Thus the special properties of volcanic ash soils are likely to be in part derived from the point of impact and overall rate of weathering, quite as much as from the nature of the original parent materials. This aspect will be referred to again in Part IV.

One further matter of importance, requiring discussion at this stage, is that the special properties of volcanic ash soils, in the farming sense, dissappear with age. There is a thus definite period in the life of the soil when these special properties dominate the land use characteristics of the soil. In the very earliest stages, there is little to differentiate recent volcanic ash from recent alluvium in respect of soil properties;

likewise, at the other end of the time scale, very old soils clearly derived originally from volcanic ash scarcely differ from soils of about equivalent age derived from rock of comparable mineral composition. This comes about logically, since with the passage of time the further weathering of the volcanic ash, often conditioned by normal leaching processes, destroys the compounds that formerly gave the soils their special characteristics. In volcanic regions where the intensity of volcanic activity has been gradually diminishing, the farmers may no longer recognise any special category of "volcanic ash soils".

Pioneers in the isolation of the special properties of volcanic ash soils arose in Japan (Kawamura, 1950; Sudo, 1951, 1953: Masui, 1954; Aomine and Yoshinaga, 1955; Egawa, Watanabe and Sato, 1955; Kanno and Arimura, 1955; and Kanno, 1956, 1962), and in New Zealand*(Birrel and Fieldes, 1952; Fieldes and Swindale, 1954); while contributory studies have been made in Chile (Besoain, 1958, 1961, 1963), U.S.S.R. (Gerasimov, 1958, 1959; Ivanova and Rozov, 1960), Indonesia (Dames, 1949; Biak, 1948; Dudal and Soepraptohardjo, 1960) and the Phillipines (De Peralta and Decena, 1940). It is now generally accepted that the special and peculiar properties of volcanic ash soils are associated with the formation of an amorphous inorganic colloidal substance, called allophane, as an early product of the chemical decay of volcanic glass. It appears in particularly large quantities during the weathering of volcanic glass derived from acid and intermediate magmas, and with the passage of time under the normal conditions of soil formation, allophane gradually transforms to other types of clay colloid, with the consequent slow dissappearance of the specific soil properties associated with allophane. So characteristic is allophane of the soils popularly known as "volcanic ash soils", that Kanno (ibid. 1962) has proposed that these soils be recognised as distinct World Soil Group and called the "Humic Allophane Soils". As will emerge during the present study of Chilean volcanic ash soils, the adjective "humic" may not always be applicable outside of Japan. This will be further discussed in Part IV, but in the meantime, there is no reason why these soils should not be collectively referred to as "Allophanic Soils" since this soil mineral is the dominant feature of their composition. Many soils in the world contain some allophane clay, particularly those derived from volcanic rocks (e.g. the soils derived from basalt in the island of Hainan in southern China, - Gerasimov, ibid, 1958, 1959), and also old soils in very cold tundra-like climates, but in none examined so far does the amount of allophane approach that present in the volcanic ash soils in the warm to hot, sub-humid and humid regions. The name "Allophanic" will be used, then, in a provisional sense throughout this account of the volcanic ash soils of Chile, to refer to those soils that contain a significant amount of allophane clay. In Chile this effectively isolates the volcanic ash soil of the sub-humid and humid cool, warm and subtropical environments.

Throughout the various circum-Pacific countries where allophanic soils have been described, there are several kinds described that have quite a close relationship with Chilean allophanic soils. However, none of these soils appear to be exact counterparts of Chilean soils, nor would any such

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* See also Birrell, 1951, 1958, 1960, 1961; Birrell and Gradwell, 1956; Fieldes, 1955, 1958; Gradwell and Birrell, 1956.

exact match be expected. Soils are everywhere a product of present and past environments, and there are possibly no two places in the world where the history of environmental change has followed precisely the same course. Indeed, there are few places in the world where present environmental conditions precisely coincide. It has been the author's special interest to compare Chilean allophanic soils with those of New Zealand, but at the outset it became apparent that the present environment under which New Zealand allophanic soils are developing differs significantly from that pertaining in the allophanic soil regions of Chile: the New Zealand soils (New Zealand Soil Bureau, 1948) occur mainly in the North Island under warm temperate climate with no well-marked dry season, whereas those of Chile occur either in a warm-to-cool climate with a well marked dry season, or in a cool, continously moist climate. There are indications of major differences in environmental histories that further widens the gap between the two groups of allophanic soils. This difference between the allophanic soils of the two countries is not immediately apparent in the soil morphology, nor is it immediately visible in the more obvious chemical and physical properties of the soils; yet is is clearly displayed in the differences in the farming pattern and in the land use characteristics of the soils of the respective countries.

The environmental history of a region is especially important where cool temperate conditions prevail, because the biological componants of an environment can have a relatively strong conditioning effect on soil development; yet even the tropical examples of Chilean volcanic ash soils (those of Easter Island) are quite distinct from the volcanic ash soils of Hawaii, Samoa (Wright, 1963 (1), in press) and Fiji (Wright and Twyford, 1963, in press), mainly because of age differences and the fact that the Easter Island soils, because of their isolation, have developed mainly under non-forest vegetation (Wright and Díaz, 1962, in press).

Thus, while it is certainly true that the allophanic soils form a distinct soil intrazonal group, whose special characteristics transcend the boundaries of the non-arid climates of the middle and low latitudes, nevertheless within the group there are many different kinds of allophanic soils, each showing a surprising measure of environmental impress. Thus, within the intrazonal distribution of the allophanic soils, there still remains a high degree of regional zonality, although this is not necessarily well displayed in the soil morphology.

B. <u>The Distribution of Volcanic Ash and Volcanic Ash Soils in Chile</u> (figs 2 and 4)

As already indicated in the first part of the introduction, the soils derived from volcanic ash fall into two well defined division: those with a significant content of allophane, and those either without allophane or with such small amounts of allophane that it has no practical significance. The latter soils occur mainly where volcanic ash has been deposited on landscapes possessing arid or semi-arid climates, but they also occur under the very cold conditions of low latitudes or high altitudes. In Chile, volcanic ash soils without significant amounts of allophane are mainly restricted to the arid and semi-arid environments of Northern Chile, although they also occur again in the southern Andes, both at high altitudes and at lower altitudes along the margin of the Patagonian desert. They are also thought to be present in "Antarctica Chilena".

The distribution of volcanic ash soils in Chile can best be discussed under two headings.

1. in the arid and semi-arid regions
2. in the sub-humid and humid regions.

1. In the arid and sub-arid regions

In this kind of environment the soils are subject to minimal weathering and leaching, but may become strongly enriched by the upward movement of soluble salts. Furthermore, the organic regime (as defined by Taylor, 1949) is exceedingly weak. With weathering at such a low intensity, and under the intensely dry conditions that prevail for most of the time, the volcanic glasses in the parent material disintegrate very slowly, and if amorphous allophane is formed at all, it certainly does not remain long in colloidal form. Since the weathering environment is saturated with cations, most probably clays such as montmorillonite, illite and vermiculite are formed in place of allophane. In any case, extremely small amounts of clay are formed in these desertic soils.

In quite a number of these soils, silica released during the weathering process may move slowly and bring about silica cementation of subsoil horizons. This is particularly noticable in some desert soils formed from siliceous rhyolitic ash.

However, in general, there is little to differentiate the soils derived from volcanic ash from other soils in the arid landscape. Under extreme desert conditions, only the highly pumiceous ash soils stand out, and then mainly because of the presence of the white pumice gravel. Under slightly less desertic conditions, weak silica cementation often occurs in pumiceous soils, (see Appendix, profile No. 1) yet be absent from other soils in the landscape. Under semi-desertic conditions, soils derived from both acidic and intermediate kinds of volcanic ash may show a minor amount of allophane formation, but this takes the form of silt rather than clay. Possibly the amorphous alumina colloid shrink to form clusters under the long interval of very dry conditions that follow the brief period when rain has moistened the soil enough to permit operation of the weathering processes, forming silt-sized compound particles which appear to be rather resistant to further wetting. Indeed, on the semi-desertic and very cold Andean altiplano of Northern Chile near the Bolivian frontier, there has clearly been some downward transportation of these silt-sized particles. They have been observed (Wright and Meléndez, 1963, (1), in press) accumulating in what are presumed to be earthquake shatter fissures in the older, underlying consolidated pumice beds. Where such beds are seasonally moistened by periodic rise of the watertable caused by melting snow or by spring water, the fissures are densely packed with a clay that appears to have all the physical characteristics of allophane (fig. 5).

Two representative soil profiles of soils derived from volcanic ash in the semi-arid region of Northern Chile are included in the appendix (profiles Nos. 2 and 3); one from the northern sector of the Chilean altiplano (profile No. 4); one from the central sector, near Ollague (profile No. 5); one from the southern sector of the altiplano (profile No. 6), and, for contrast, one from the colder, semi-desertic margin of the Patagonian pampa, far to the south of the other locations (profile No. 7).

An interesting occurrence of allophane in the marginal desert regions was noted in the soil materials deposited in the basin of the great Salar de Atacama. Here, intense evaporation promotes a strong upward movement of soluble salts from the highly saline watertable. These salts accumulate in the predominantly sandy alluvial strata and form very strong salt crusts. Interleaved amongst these salt-cemented strata, there are fine layers of weathered volcanic ash, of mainly andesitic origin. These layers appear to contain a large amount of allophane, which apparently this clay resists, or cannot provide the requisite conditions for, accumulation of soluble salts, while not interfering with the normal upward passage of such salts from the saline watertable below. These clays are moist and not salty to the tongue. So marked is this phenomenon, that a thirsty man can, with patience, relieve his distress by masticating lumps of clay extracted from between the salt crusts. (Meléndez and Wright, 1963 (ii), in press).

Another example of the occurrence of allophane under desertic conditions may be found where alluvium derived mainly from volcanic ash is kept under permanent irrigation. Desert irrigation projects are scarce in Northern Chile, but in the Lluta valley where irrigation is carried out using strongly acid waters originating in volcanic springs at the foot of Tacora volcano (Zambrano and Urrutia, 1961), allophane clays are appearing in some alluvial soils as a result of the weathering of volcanic glass. Much of this colloidal clay aggregates on drying and forms silt-sized particles, which are removed by the wind and usually accumulate on the lower slopes of the steep valley sides (see Appendix, soil profile No. 8). The main part of this allophane, however, remains in the soils and imparts unexpected problems of phosphate fixation to what is essentially a normal-looking irrigated desert soil, (Melendez and Wright, 1963 (i), in press).

These examples of the occurrence of allophane in arid and semi-arid environments are rather exceptional: as a rule allophane, as an important soil constituent, does not appear in Chile until the sub-humid zone is reached, - in a about latitude 35° S, where the mean annual rainfall approaches 1000 mm and the soils are quite moist for at least four months of the year.

Near the margin of this sub-humid region, in a zone where the modal soils are mainly Non-Calcic Brown soils and grumosols (Roberts and Díaz, 1960), there are occasional remnants of old valley floor materials formed mainly form siliceous rhyolitic pumiceous volcanic materials*. These soils (see Appendix, soil profile No. 9) contain no recognisable allophane, but are notable for the high degree of silica cementation in the subsoil. Beyond this point, southwards, all volcanic ash soils (except those of great age) contain allophane in significant amounts.

2. In the sub-humid and humid regions

In Chile the region of most intense volcanic activity (from Quaternary time onwards) coincides, rather well, with the region of increasing soil humidity. Thus, in Chile, the farmers recognise a well defined region of "volcanic ash soils", - which we can now interpret as a region of soils significantly rich in allophane. These allophanic volcanic ash soils of Chile are known by two local names, both of indigenous origin. The well drained soils are known as "trumao", meaning soils with light, dusty properties; and the seasonally wet, seasonally poorly drained soils, are known as "ñadi" soils. Ñadi is an Araucanian Indian word used to indicate land that was swampy, but with a firm subsurface so that it was transitable with care. "Trumao" and "ñadi" are exceedingly useful local names for two major divisions of the Chilean allophanic volcanic ash soils, (Wright, 1963(ii).

The well drained (trumao) soils are associated with a wide variety of landforms, ranging from steep Andean ranges to flat lowlands. Their parent materials are mantling deposits emplaced by sub-aerial agencies, directly or indirectly, and sometimes by alluvial agencies, or as a thick "sludge" of water and mineral matter.

Those of direct sub-aerial origin are located mainly on the slopes and foothills of the Andean cordillera, often occurring on very steep slopes (Wright and Mella, 1963(i); Wright, 1963 (iii), both in press). Those of indirect sub-aerial origin occur mainly along the outer foothills of the Andes where volcanic loess (dust consisting mainly of volcanic minerals) has accumulated by the action of the prevailing westerly winds blowing across the plains and terraces of the Central Vale and across wide river beds and picking up loose particles of volcanic alluvium in their passage across the landscape and redistributing them over the Andean foothills. A rather similar type of "volcanic loess" has from time to time accumulated in places along the coastline where the same westerly winds have sifted fine materials from coastal dunes and lifted loose particles from coastal drift deposits on terraces that have been from time to time uplifted during seismic movements.

Volcanic soils of alluvial origin are widespread on the central lowlands of Chile, sometimes showing by their broad, sweeping fan-like outline, that they were the product of local and intense volcanic activity which on one or more occasions completely overloaded a river system. Soils originating from mudflows and sludge-like deposits, are of more local occurrence, and can usually be related to some specific type of volcanic activity (Wright and Espinoza, 1962), or even seismic activity (Wright and Mella, 1963 (ii), in press).

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* See also Borde, 1955.

The less well drained (ñadi) soils are nearly always found on flattish or slightly rolling areas of the central vale in the south-central provinces of Chile (Rodríguez, 1948; Díaz et al, 1958; 1959).

The distribution of trumao and their various derivative soils, (fig. 4) commences with the appearance of small scattered areas in the Andean cordillera immediately north of the Maule River (latitude 35°S). Thence, proceeding southward, trumao soils occur with increasing frequency in the foothills of the Andes, until they form an almost complete mantle in about latitude 36°30'S. On the lowlands, scattered patches of trumao-like soils of alluvial origin appear in latitude 35°30'S, and these grow more extensive to the south, until in about latitude 39°S almost the whole of the land between the Andean ranges and the sea is occupied by trumao or trumao-like soils. Further to the south, the ash mantle on the Andean ranges is very thick and complete, but does not extend (except in a few places) to the coastal ranges; in these latitudes, the ñadi soils appear on the plains and terraces of the Central Vale. This pattern is continued on the Chiloé Island, while on the very steep and dissected mountains of the Andes on the mainland opposite, the sub-aerial ash mantle continues unbroken, except where removed by in historic times by man-induced erosion. At the latitude of the southern port of Aisén (latitude 45°S) the trumao soils still cover the undisturbed hill and mountainsides, and further extend westward into Argentina where their allophanic properties diminish owing to increasing dryness and coldness of the Patagonian climate*. Allophanic soils continue well below latitude 50°S, but are somewhat restricted to a narrow more humid foothill region on both sides of the Andean chain. At high elevations, and on the western Patagonian pampa conditions are too cold or too dry for the formation of allophane in significant amounts in the soils. On the hills east of Punta Arenas (latitude 53°S), there are podzolised soils which are in part formed from volcanic ash, but the amount of allophane in their profiles (see Appendix, profile No. 10) is very small. In these latitudes, most bog soils have layers of volcanic ash clearly preserved in the peaty profile (see also Auer, 1950). By studying the extent of these ash layers it is possible to be certain that volcanic ash constitutes a part of all the soils in the Magallanes Province. Yet allophane is not a significant feature of any of these soils.

This brief resumé of the distribution of volcanic ash soils in Chile would be incomplete without mention of the allophanic soils of Easter Island, the westernmost outpost of Chilean territory, 2000 miles from the Arauco peninsula, the nearest point on the South American mainland. The volcanic ash soils of Easter Island (Díaz, 1949; 1951; Wright and Díaz, ibid) are somewhat older and more basic in origin than most of the volcanic ash soils of the Chilean mainland. They occur mainly on the old volcanic cones where they are in part mixed with weathered scoria. Related soils, possibly formed from a type of loess rich in volcanic minerals rasped from the steep cliffs surrounding most of the island by the persistent trade winds, occur in patches throughout the island. Three Easter Island allophanic soil profiles are included in the Appendix (Nos. 45, 46 and 47) and are described fully in Part IV.

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* See also Wright, 1963 (iv).

There are many volcanic ash soils in the sub-humid and humid zones of Chile that do not achieve recognition as trumao soils. These are all older volcanic ash soils, in which the weathering process is most advanced and amorphous allophane has been largely replaced by hemi-crystalline and crystalline clays like halloysitic and kaolin. These soils no longer have the morphological, chemical, physical, nor the farming or engineering, attributes of trumao and ñadi soils: in Chile they are known collectively as the "red volcanic clay" soils, and they fall outside the terms of this enquiry, although some intergrades between these soils and trumaos are mentioned again in Part IV, and a brief discussion on the possible origin of these soils is included as Appendix II.
There are important pedological and farming differences amongst the various kinds of trumao and ñadi soils, and these will be considered in greater detail in their proper place, which is Part IV. However, before closing this introduction, it is well to remember that from time to time, almost the whole of the Chilean atmosphere must have been charged with fine volcanic dust, and every soil in the country likely contains some minerals of volcanic origin that are not representative of the local rocks. The proportion may be small, as judged by the remaining resistant minerals (see also León, 1962), but the total contribution over the centuries may be considerable, and may account for some degree of similarity that may be observed throughout the Chilean soil assemblage. This may be even more true of the soils of Argentina, a patient land that has accepted without protest many million tons of volcanic dust blown across from volcanoes on the Chilean side of the Andes.

The common properties of Chilean allophanic volcanic ash soils are discussed in Part I of this report, together with a brief summary of the main kinds of allophanic volcanic ash soils occurring in Chile.

PART I

ALLOPHANIC VOLCANIC ASH SOILS OF CHILE: GENERAL CHARACTERISTICS, FORMATIVE ENVIRONMENT, AND MAIN KINDS OF SOIL

a) General characteristics

The general characteristics of allophanic volcanic ash soils in Chile are as follows:-

1. The whole soil profile tends to be mellow and friable, usually with clearly distinguishable depositional stratification, and with a distinct colour difference, sharply defined, between the topsoil and the subsoil. Occasionally one or more of the subsoil layers may be pumiceous and cemented.

2. Topsoils range from brown to nearly black, and the natural colour (as visible under the natural plant cover) persists for a long time after the onset of farming, even where no particular effort is being made to sustain the organic matter content of the surface soil. Textures are usually loam, with varying amounts of sand and silt.

3. Subsoils are noticeably more yellowish than the topsoils; in extreme cases yellowish-brown or yellowish red, in colour; ranging in texture from loam to clay loam, and usually with a high content of silt (part of which may be aggregated clusters of dried amorphous allophane). When completely dry, the powdered soil behaves like fine sand and is slow to rewet, but often the soil is only apparently dry and when squeezed firmly between finger and thumb, there is an abrupt sheering sensation, and the soil becomes moist, with a rather "slippery", "soapy", or "greasy" feel. Naturally moist soils, have an easily recognised greasy feel, and under pressure they become "smeary" or, when rubbed strongly for some time in the palm of the hand, the soil material may almost become liquid. All of these are useful tests for the presence of allophane in appreciable quantities.

4. Deeper subsoil horizons are nearly always depositional strata, and may vary widely in nature; their boundaries are often very distinct and marked by abrupt changes in texture, compaction, consistence, etc.

5. Seldom, if ever, are the qualities of stickyness or plasticity pronounced in the topsoil or upper subsoil horizon of allophanic soils. If these appear in the lowermost strata, it is usually an indication that the passage of time has permitted the change of allophane clay towards meta-halloysite or one of the other structurally orientated clays.

6. The whole soil has a very low bulk density, expressed as a notable "fluffyness"; has low volume weight, and the peds are usually quite porous. When thoroughly dried, peds are often difficult to rewet, and may float when thrown into water.

7. The upper soil horizons have a high water-holding capacity, and a high water-retaining capacity when once thoroughly wet. The upper subsoil horizon may develop very prominent shrinkage fissures on drying. Both top-soils and subsoils form long ice pillars and needless where roadside cuts are exposed to heavy frost; frost heaving of the topsoil is commonplace on ploughed land in winter.

8. There is usually intense fibrous root development in the topsoil but relatively few tree roots penetrate into the deeper subsoil layers.

9. The soils range in acidity is comparatively narrow (pH 6.3 to 4.5) considering the wide range in base status (2%-90%). Most of the allophanic soils lie within the range pH 5.9 to 5.4, yet within this range may occur soils ranging in saturation from 70% to 5%. In other words, the high iso-electric point of allophane tends to result in a misleadingly high soil pH reading, although the actual base status of the soil may be quite low. The pH value alone cannot be relied upon to give an accurate lead to the plant nutrient status of the soil.

10. Chilean allophanic soils have characteristically a high base exchange capacity; a high anion exchange capacity, and a very high rate of phosphate "fixation".

11. The soils are difficult to disperse properly for textural determination. Soils that are essentially clays by definition in properly dispersed material, have field textures no heavier than silt loam or even fine sandy loam. Proper dispersion may usually be achieved by treating the soils with hot dilute peroxide solution, washing on a Buchner funnel first with water and then with N/20 hydrochloric acid, then again with water, and dispersing finally in sodium hexametasulphate solution at a strength of 3 grams per litre (Birrel, pers. comm. 1960).

12. Total nitrogen is high to a remarkable depth in these soils, and this is often accompanied by such a high total carbon content that the C/N rations are commonly unusually high for a considerable depth down the soil profile.

13. On analysis by X-ray and D.T.A. equipment, and from inspection of electron microscope photographs, Chilean allophanic soils (Besoain, ibid, 1958; 1961; 1963, in press) have allophane as the dominant mineral in the clay fraction. Besoain also reports that many Chilean allophanic soils have considerable quantities of gibbsite present, even in the upper part of the subsoil horizon. In this the Chilean soils differ from New Zealand allophanic soils where gibbsite appears mainly in the lower horizons and strata. In

the lower strata of some Chilean allophanic soils, where weathering of the older depositional materials is more advanced, kaolin and amorphous silica have been found along with halloysite, hydrated halloysite, gibbsite and hydrous oxides of iron.

14. The soils have a relatively high content of exchangeable alumina and also contain free alumina compounds.

Many of these characteristics of the Chilean allophanic soils are precisely those proposed for a new world group provisionally called Humic Allophane Soils (Kanno, ibid, 1956; 1962), except that the topsoils of the Chilean soils are less melanised (i.e., less dark and less rich in organic matter). In Japan, the topsoils of many Humic Allophane soils have a humic fraction which contains highly polymerised and condensed black humic acids, of a high C/N ratio and high molecular weight. It has been shown that aluminium and allophane are in combination with fulvic and other humic acids. This had not been investigated in the Chilean counterpart soils, but is unlikely to be so pronounced as in the Japanese soils. Birrell (pers. comm., 1963) also reports that many of the Japanese Humic Allophane soils are extremely acid, far more so than New Zealand (and also Chilean) soils developed under equivalent climatic conditions.

By the properties enumerated above, it is clear that the Chilean allophanic soils are within the general concept of Kanno's Humic Allophane group, but that the characteristics at present defining the group would need some slight modification to embrace all the Chilean allophanic soils.

b) The Formative Environment

Within the general limits of humidity and temperature set out in the Introduction, the allophanic volcanic ash soils of Chile cover a rather wide range of environment. The approximate range of the current environmental characteristics (climate, topography, parent materials, and natural plant cover) is set down below. These are not only of interest to scientists studying soil genesis, but have considerable bearing on land use practices and matters discussed more fully in parts II and III.

1. Climate

Precipitation: at the dry extreme, allophanic soils occur under a precipitation of somewhat less than 1000 mm per annum, with a very unequal distribution in that there are no less than five continuously dry months (in which the monthly rainfall is less than 60 mm), although rarely does any month have less than 10 mm. In this area evaporation rates during the dry summer months are very high.

At the other extreme of their moisture range, allophanic soils occur under a precipitation of over 4000 mm per annum, with no well marked dry season. Some areas regularly experience winter snowfalls up to 3 m in depth, lasting on the ground for one or two months; other areas are virtually frost free (e.g. parts of Chiloé Island) throughout the year (see figs. 6A and 6B).

Temperature: The average mean annual temperature ranges from about 15°C to less than 8°C; with a winter (July) range of less than 1°C to about 8.5°C; and an average summer (January) range of around 13°C to over 20°C. Freezing and thawing phenomena are characteristic of some areas, absent in others. (see fig. 7).

2. Topography (fig. 8)

As indicated briefly in the Introduction, allophanic soils may be found on almost any type of relief, from the extremely rugged and precipituous slopes of the southern Andes, to the flat plains and terraces of the central vale. The topography perhaps most characteristic of the Chilean trumao soils, is the strongly rolling to undulating "ceja de montaña" strip of foothill country extending along the face of the Andes from Chillán to near Villarrica. This is a most important farming region, but here the soils are only in part derived directly from subaerial volcanic ash: mainly it is a region where soils derived from re-sorted and re-deposited volcanic loess. The true subaerial volcanic ash soils are found further in towards the volcanoes, usually on steeper hill slopes, and as steepland soils amongst the ranges. On the plains of the central vale, the allophanic soils are mainly derived from volcanic loess and from volcanic alluvium; and along the coast there are some areas of rolling landscape covered with allophanic soils derived mainly from loess originating from coastal drift materials.

3. Parent materials:

The most obvious difference in the soil parent materials lies in the presence or absence of pumice fragments, and the proportion of angular or rounded quartz sand. Pumiceous and conspicuously sandy volcanic materials are more common in the south of the allophanic soil region (from Llanquihue Province southwards), but highly pumiceous areas also occur in the high cordillera at several places north of this limit. There is also a visible coarsening of the ash materials along any radius towards a volcano, ending at the point where all ash is obscured by coarse scoria and similar large ejecta or by recent lava. Stratification of the ash beds also increases along any radius towards the volcano. At some distance from the vent, where all ash is of a fine grade, stratification of the beds is sometimes very difficult to make out without laboratory investigation of selected samples.

Few minerological studies have been made of the Chilean ash materials, except in the case of some recent volcanic eruptions (e.g. León and Polle, 1956). General observations show that the great majority of the ash beds in Chile are of intermediate to acid origin: basic volcanic sands are comparatively rare, occurring chiefly in the Los Angeles area where they originated from

Antuco volcano, and descended on the lowlands as a sudden sand flow connected with the rupture of a lava barrier across the front of Laguna del Laja; also over smaller areas near Llaima volcano; and in the vicinity of some of the more southerly groups of volcanoes, including several areas in Aisén Province.

4. Natural plant cover:

To a Chilean, the typical natural plant cover associated with trumao soils is the roble (Nothofagus obliqua); but this is true only over a limited part of the whole extent of trumao soils, - the sector between Chillán and Puerto Octay, along the face of the Andean cordillera. Elsewhere, trumao soils are associated with broadleaf evergreen forests (the "laurel" forests with abundant Laurelia sempervirens, L. serrata, Drimys winteri, Aextoxicon punctatum, and, especially in the south, Eucryphia cordifolia); with mixed forests containing podocarps such as the mañio (Podocarpus nibigenus) and coigüe (Nothofagus dombeyi); with alerce forests (Fitzroya cupressoides), - although this magnificent timber tree has been cleared from most areas of trumao soils; with "north Patagonian rainforest (Schmithüsen, 1956) dominated by coigüe, but with associate species of Weinmannia, Saxegothea, Laurelia and Nothofagus nitida; with ñirre forest (Nothofagus antarctica; and with lenga forest (Nothofagus pumilio). In addition to the above types of forest cover, trumao soils also may be found with savanna-parkland natural vegetation in which the ground cover is grass, with numerous scattered bushes of Acacia cavena ("espino") and large isolated roble trees; and under a continuous low shrub vegetation dominated by maqui (Asistotelia sp.). In coastal areas, some small patches of trumao carry evergreen forest with abundant litre (Lithrea caustica), boldo (Boldea boldus) etc.

Ñadi soils, by way of contrast, are associated with a much narrower range of natural vegetation. The typical ñadi forest of south-central Chile contains laurel (Laurelia sempervirens), olivillo (Aextoxicon punctatum), canelo (Drimys winteri), ñirre (Nothofagus antarctica), lenga (N. pumilio), coigüe, arrayan (Myrceugenia apiculata), avellano (Gevuina avellana) and ulmo (Eucryphia cordifolia). The forest is not of large stature, but it varies but little over its range from north to south. If anything avellano and arrayán are more frequently encountered in the northern ñadi forests, and ulmo is more common in the south. Some of the shrubby species of the second tier, are even more typical of ñadi soil conditions: amongst these radal (Lomatia obliqua), maitén (Maitenus boaria), quila (Chusquea quila), Taique (Desfontainea spinosa), and Tiaca (Calcluvia paniculata), are reliable indicator plants. In the extreme south of the ñadi range, the typical ñadi forests merge with the Nothofagus dombeyi - Weinmannia trichosperma forests of the north Patagonian rainforest. A generalised map of the natural plant cover is shown in fig. 9, following an earlier map by Pisano 1950).

c) The Main Kinds of Allophanic Soils

At the present time there is insufficient laboratory information to define accurately the limits of the main kinds of allophanic soils derived from volcanic ash in Chile. At this stage, the best course is to indicate the nature and probable inter-relationships between the main kinds of known soils (and there are probably some important kinds of allophanic soils as yet undiscovered) and to indicate what additional laboratory information is required before the situation can be finally resolved.

At the outset, it is obvious that the allophanic volcanic ash soils of Chile fall into two main divisions: the soils without drainage impedence, - the trumao soils; and those with some drainage impedence, - the ñadi soils.

Within the trumao division, there are approximately five main sub-divisions which can be approximately characterised by differences in the apparent degree of weathering, leaching and melanisation (humus incorporation). These are environmental factors operating during soil formation, and they operate not only on trumao soils but on all the other kinds of soil in the vicinity. Thus, by studying these other, somewhat older soils associated with trumao soils, one is able to get a more comprehensive idea of the regional environmental impress on soil formation, than if the, generally younger, trumao soils were studied alone. By thus extending the scope of the enquiry, one can delimit with greater surety the approximate boundaries over which the present strength of the weathering, leaching and melanising factors are operating with about equal force. Using this technique, a map showing the approximate strength of these factors has been prepared (fig. 10). There are six principal weathering categories: slight, slight-to-moderate, sub-moderate, moderate, and moderate-to-strong, and strong-to-very strong. The latter category is restricted to Easter Island. Within these six categories, the soils show varying degrees of leaching and melanisation, which accord fairly well the recorded rainfall data, temperature data, and age of the soil, and other factors influencing the intensity of the soil process.

In the first weathering category, belong the scattered patches of trumao in the Andean foothills of the provinces of Talca and Linares; their derived alluvial and colluvial associates on the Central Vale; a very small area of related soils, somewhat pumiceous, around Laguna del Maule (at an altitude of 2.100 m); a few patches of volcanic loess along the coast near Tregualemu; and some small areas of trumao at the margin of the Patagonian pampa between latitude 45°S and 46°S. These soils are all of minor extent, but they are all no more than slightly weathered, and they all exist under relatively weak weathering environment; although they differ amongst themselves rather widely in age, in degree of leaching and in degree and type of melanisation. These are the "extreme northern" examples of allophanic volcanic ash soils in Chile.

In the second weathering category, where the present weathering impress is slight-to-moderate, we have the main area of trumao soils of the Andean foothills and ranges stretching from north of Chillán to south of

Los Angeles; together with their derived alluvial and colluvial associates. Patches of recent volcanic ash, in which weathering is only just commencing occur near certain volcanoes, but apart from these, the degree of weathering appears to be fairly uniform over the zone, and the main variations in the soils are due to leaching and melanisation. These soils represent the "northern" group of allophanic volcanic ash soils.

In the third category, where the present weathering impress is sub-moderate (i.e. rather more than in the preceding zone but less than "moderate"), we have an important area of trumao soils centred about the Province of Cautín. In this zone, trumao soils extend from near the coast right to the Argentinian border, and include soils derived from volcanic loess, volcanic alluvium, coastal drift (volcanic) loess, and subaerial volcanic ash, some of which is markedly pumiceous. Soils range from slightly leached to very strongly leached, and from weakly melanised to strongly melanised. These soils represent the "modal" or "central" group of allophanic volcanic ash soils in Chile.

In the fourth category, where the weathering impress can best be described as moderate, are the trumao soils of Valdivia, Osorno, Llanquihue and part of Chiloé Provinces. Here again, there are trumaos of various and origin, ranging from slightly leached to strongly leached, and from slightly melanised to very strongly melanised. These soils represent the "Southern" allophanic volcanic ash soils.

In the fifth category, where the weathering impress is moderate-to-strong, we have soils in the south of the island of Chiloé, in "Chiloé continental", and in the southern province of Aisén. Here most soils are fairly strongly leached and melanised, although the type of melanisation varies rather widely. These soils are the "extreme southern" type of allophanic volcanic ash soil in Chile.

In the sixth and last weathering category, we have only the soils developed near the volcanic cones on Easter Island, and their related loessic volcanic soils. These soils represent the Chilean "tropical" allophanic volcanic ash soils.

With the exception of the sixth category, in which near tropical temperatures have markedly accelerated the rate of weathering, the remaining five categories cover a relatively small range in mean annual temperature (from about 15°C in the north to about 8°C in the south, and the weathering environment is clearly controlled more by the mean condition of soil humidity and by the pattern of the rainfall, than by mean air temperatures or by the total precipitation. The five weathering categories correspond quite well with the mean length of the summer dry season: the somewhat cooler but continuously moist soils of the southern part of the trumao range are continuously moist soils and are thus subjected to considerably more weathering than the rather warmer soils of the northern sector where the soils are relatively dry for nearly half the year.

Admittedly, this subdivision of the trumao soils of Chile is still largely an experimental one, and much essential laboratory data is still needed (more particularly mineralogical investigations), but, as will appear in the succeeding parts II and III, this subdivision does accord reasonably well with land use practices and with farming experience. In some cases the suggested subdivision of the trumao soils cuts across soils that, up to the present time, have been mapped as a single pedological unit, - for example the old Santa Barbara trumao soils have been divided into two parts, the northern part carrying the old name and the southern part being provisionally named Cautín trumao soil.

In the case of the ñadi soils, where soil processes are in part strongly influenced by seasonal waterlogging, low oxygen content and the seasonal development of soil gleying processes, they can be regarded as either a single unit ("allophanic volcanic ash soils with drainage impedence") or can be regarded as poorly drained allophanic soils related to specific trumao soils of their particular weathering region. Ñadi soils first appear in the third weathering zone, reach their maximum expression in the fourth zone, and dissappear as a distinct entity in the fifth weathering zone, it may therefore be more convenient to regard them, as is the present policy in Chile, as a group quite distinct from the trumaos. In this case, the ñadi soils, as a distinct group, have moderately gleyed representatives near the northern limit of their range, and are strongly gleyed over most of their range, becoming transitional to podzolic gleys at their extreme southern limit. Regarded in this light, as a group, they belong to the Humic Gley category of the soils of the World, but deserve some additional distinction since they are transitional to Humic Allophanic soils.

More detailed information on the nature, origin and classification of the allophanic volcanic ash soils of Chile will be found in part IV.

PART II

USE, MANAGEMENT, AND PRODUCTIVITY OF THE MAIN KINDS OF ALLOPHANIC VOLCANIC ASH SOILS OF CHILE

Introduction

Farming endeavour on the allophanic volcanic ash soils improves as one goes from north to south, reaching maximum effectiveness in the agricultural region of Osorno. The farming trend is thus directly opposite to the general trend of soil fertility, as measured by the soil base status. To a large degree this apparent anomaly is due to steadily improving soil moisture conditions in the summer, offsetting the increase in soil leaching occasioned by increasing rainfall; but it is also derived from a combination of several historical, sociological and psychological factors.

Some of the allophanic volcanic ash soils have been under cultivation for many centuries. Both the Araucanian race, and probably some of their primitive predecessors, engaged extensively in subsistence agriculture. It is believed that the Incas, who came victoriously south as far as the northern limit of the allophanic volcanic ash soil, finally devised a system for bartering maize and other northern cereals for potatoes and similar agricultural products grown by the unconquerable Araucanians of the land further south, (Latcham, 1924).

After the Spanish Conquest, only the northernmost part of the trumao soil became available for colonisation. Throughout Spanish colonial times, and even for many decades during the early life of the Republic, the main (central) area of trumao soils remained wholly the dominion of the Araucarian race. Thus, in the time scale of Chile, farming started relatively late on a great many trumao soils. Most of the soils in the Province of Cautín, all the soils of Valdivia and much of the soil of Osorno Province were unavailable to Spanish and to the early Chilean colonists. Indeed, there are still many areas reserved specifically for Araucanian tribal farming in each of these three provinces. Beyond the southern boundary of the Araucanian territory, which was near Osorno, first Spaniards and, later, Chileans, were in occupation and were farming the land from quite an early date; but this region (which includes Chiloé Island, and parts yet further south) was so distant from the capital city, Santiago, that the farmers remained for a long time completely dependent upon their own resources. Thus, the pattern of agriculture that emerged in these southern provinces was far removed from the typical pattern of the latifundia that became established over the northern sector of the trumao soils. In the south, it is true that some latifundia came into existence, but the basic agricultural pattern was one of subsistence farming, and for many decades only a minor amount of produce was 'exported' to Santiago and the central Government (Lima). As the Araucanian race gradually became absorbed into the framework of the Republic, a part of the main central area of trumao soils became available for more intensive agricultural development, but by this time the technical level of farming was much more advanced. So yet a third agricultural pattern appeared, in which latifundia, minifundia, squatter-farmers and tribal farmers were delicately intermingled. At a still later date, when there was an exodus of farmers from Europe, many distinct racial communities were encouraged to settle in the central and southern trumao areas. If this influx did not greatly change the emergent agricultural pattern, it at least brought some new ideas and new techniques to the region.

Thus the impact of agriculture has been quite different in the three trumao soil regions. In the different regions, agriculture started under diverse conditions, at widely different times, and within a varying economic framework. There are still significant sociological and psychological differences between the farming groups of the different trumao regions, differences which, to this day, partly obscure the influence of inequalities in basic soil properties. Indeed it is not uncommon, in Chile, for the rate of progress of farming often to be related more closely to the history of land settlement than to intrinsic soil properties.

a) Present patterns of soil use

Under this heading a brief resumé will be attempted of the main kinds of land use at present to be found on trumao and ñadi soils.

Central Chile is justly noted for the wide range of crops that can be grown, but the list shortens appreciably in the zone where trumao soils first appear. Crops that can still be grown include wheat, barley, rye, maize, oats, flax, potatoes, rape-seed, sugar-beet, sunflower-seed, clovers and pasture grasses. There is a further restriction of this list in the region of the southern trumao and ñadi soils, where increasing cold and higher rainfall make, for example, maize growing, sunflower seed and rape seed production more uncertain and much less profitable.

In general, the agricultural potentialities of the northern trumao soils (those between the Maule and Malleco rivers), are but poorly realised, with the exception of the irrigated volcanic alluvial soils where excellent farms may be seen. In this region, wheat is commonly regarded as an essential cash crop; and the long grass fallows needed to recuperate the soils after a period of wheat cropping are regarded as an unavoidable nuisance, and few farmers make the attempt to utilize this excellent opportunity to establish high-producing pastures for fattening livestock. This northern region is, above all, a region of "latifundistas", many of whom have far more land than they can properly farm, and the profits from the wheat crops (which move each year, in long rotation over the wide landscape) are more than sufficient to satisfy the owner of the land who rarely, nowadays, lives continuously on the property. Thus, the great agricultural advantages of these trumao soils for livestock farming are generally neglected, and the great majority of "pastures" seen nowadays on these soils consist of volunteer grasses and herbs, most of them of low nutritional value for grazing. By contrast, the southern trumao soils are sown to a much wider range of arable crops and the rotation system is tighter and more carefully planned. The central (Cautín) trumao soils are handled in a manner that is about intermediate between the two extremes. In the south the traditional grip of wheat has been well and truly broken (if, indeed it ever achieved an opportunity to dominate farm psychology). In the central region, cereal crops are to-day giving ground to more diversified farming. In both central and southern regions, far more use is made of the grass fallow period between crops than in the northern trumao zone. In the centre and in the south, the trumao soils may be seen emerging in their true colours; namely, magnificent soils for rearing and fattening livestock, and for dairying.

The present day pattern of agriculture on trumao soils is closely related with landforms. In the ranges of the Andean cordillera, much of the trumao soil is still in forest; in part this forest is being selectively milled, but part is still relatively untouched. Here, penetration of agriculture is restricted to families of settlers, often virtually 'squatters' since they are without title to the land, who have cleared small patches of the hilly land and most of the narrow alluvial flats, to enable a livelihood based on a mixture of cereal cropping, subsistence cropping, and on charcoal burning. It is regrettable that these pioneering families are often the cause of serious (but usually unintentional) damage to the surrounding forest; yet it is they who are primarily responsible for the most of the forest fires that occur every summer. Such fires inevitably result in severe erosion of the surrounding steep ash-covered slopes of the cordillera.

A more closely organised type of agriculture is developed on the outer foothills of the Andes, where much of the land is virtually the inland extension of large latifundia whose central operations are on the plains and terraces of the central vale. On these trumao-covered foothills, most of the original forests have been clear felled and, after a period of cropping in wheat and oats, have either been allowed to revert to natural pasture, or are maintained mainly in pasture but are cultivated and sown down to cereals at irregular intervals. Characteristically, these trumao hill soils still have a sprinkling of large roble trees, left to provide shade for livestock, and timber for various purposes. The trees appear strangely tufted because are usually trimmed each autumn to provide firewood for the workers on the estates. Since most of the cultivation is carried out by teams of bullocks, the presence of these large trees is not a major obstacle to crop production, although it is often very noticeable that the presence of the trees leads to great variation in ripening and in yield within fields of oats or wheat and, especially, flax.

The trumao soils of the rolling downlands and high terraces that front the lowland plains and lower terraces are commonly very intensively used. Formerly (and in some places, it is still the custom) these soils where subjected to a regime of continuous cropping. Year after year cereal crops were harvested, until it became apparent that serious loss of fertility, and loss of soil material by wind erosion, was markedly lowering the productivity of the land. Nowadays, more enlightened farming, with short and long rotation pastures interspersed between one or two years of cropping is becoming general; except on farms that are rented out solely with the idea of making quick profits from the land. Unfortunately, there are far too many farms operated on this basis in Chile.

The trumao soils of the plains and lowlying terraces are almost universally very well farmed. On many farms, local irrigation systems have been contrived, and the standard of farm management is frequently high. Sugar beet growing now supplements cereal cropping, and both crops can provide a farmer with something approaching a stable, guaranteed, farm income. As a result of more assured returns, farmers are finding it possible to modernise and mechanise their methods. An appreciable proportion of the dairy produce of Chile comes from the southern trumao soils, and also a large amount of fattening is carried on.

According to Roberts et.al. (1958), the acreage of wheat grown on trumao soils was about 374,000, or almost 50% of all the wheat grown in Chile at that time. The average yield was 20 quintals per hectare, which is low, but yields of 35 quintals per hectare could be achieved in good years. In the case of oats, about 88% of all the oats grown in Chile came from trumao soils (in 1958), with an average yield of 16 quintals per hectare, and with yields of up to 50 quintals in good years.

The ñadi soils are only at the beginning of their agricultural history since they have been farmed for rather less than 100 years. In the early days the labour of clearing the forests and draining the land, greatly limited the actual area that could be brought under farming. Now, with Government assistance, a serious attempt is being made to incorporate these soils into the agricultural economy of the country. The ñadi soils require skillful farming, and when properly managed grow excellent crops of potatoes, sugar beets, oats, wheat, flax; and, moreover, make excellent pastureland for dairying, and for fattening cattle and sheep. There are about 700,000 hectares of ñadi soils, but rather less than half of this area is being profitably used at the present time.

The allophanic volcanic ash soils of Chile thus form a very important item of the national assets, and any soil research and experimental soil management trials carried out on these soils must sooner or later find reflection in the improving agricultural economy of the country. It must be remembered, however, that the use of these soils is by no means exclusively agricultural: about two-thirds of the total allophanic soil area has a far greater forestry than an agricultural potential. Indeed, in many places, an extension of agriculture on to the ash-covered steep hillsides in the southern zone can only lead to further disastrous erosion, as is very evident from the situation in Aisén Province (Wright, 1963, in press). Allophanic soils also have importance for the engineers, since they are endowed with many peculiar physical properties that require special engineering treatment (Díaz, 1959; Wright, 1961).

b) Soil management

1. General management practices

There is considerable uniformity of management practices throughout the trumao soil region; a similar, but slightly different set of management practices are in vogue throughout the ñadi soil areas. Where atypical practices are in operation, they are usually dictated by special landforms or by factors relating to availability of irrigation water. The paragraphs that follow then, are applicable to the majority of farms on trumao and ñadi soils, - they refer to neither the best nor the worst, but to the average kind of farm and farmers, - and they more specifically relate to the trumao soils of the rolling and undulating downland that extend along the foot of the Andean cordillera.

In preparing land for arable crops, the old pasture is broken either with a single furrow moleboard plough drawn by oxen or horses, or with tractors drawing multiple-furrow moleboard ploughs or heavy disc ploughs. There appears to be a universal tendency amongst farmers to plough too late and too deep. Ploughing usually starts in late spring or late autumn, when the amount of feed in the pasture has diminished with the onset of drought (late spring ploughing) or cooler temperatures (late autumn ploughing). The ploughing process is often a hurried one, and the job is seldom well done. A good deal of the original turfy pasture is left with its original roots still attached to the soil, and the land surface is usually left in a most uneven condition. In the case of late spring ploughing to prepare the land for autumn sown wheat, a summer fallow is arranged. During this fallow, there is generally spectacular growth of weeds, amongst which is an abundance of 'chépica' grass (Agrostis sp.) which sprouts readily from rhizomes only partially severed during ploughing. Chépica is accompanied by other annual and perennial weeds of all types. Often little is done to check this weed growth until near the time of sowing, when, what virtually has become a newly sodbound volunteer pasture, is cultivated to some extent with a disc harrow, or some similar implement, to prepare a seedbed.

On this rather unpromising seedbed, seed is broadcast by hand and subsequently disc harrowed to cover the seed. If fertilizers are being used, phosphate may be also broadcast at this time. Relatively heavy rates of seeding are customary to combat the subsequent losses due to weed competition, and to replace loss due to attacks from ground-living insect pests. Most seedbeds are, alas, very 'turfy', roughly prepared and unevenly consolidated. Germination is often patchy and the young plants usually show very distinct signs of nitrogen deficiency. Wheat is the main autumn sown crop, and sowing rates are often in excess of 160 kg per hectare, while phosphatic fertilizers (often the relatively soluble types like "Bifos", "Guano Rojo", and superphosphate) are applied at rates of 80-120 units per hectare, and are nearly always broadcast.

During the growth of the crop, it may be observed that the great majority of the plant roots show a decided disinclination to penetrate far into the subsoil; and a mature plant often shows a root system that consists virtually of balls of short, close-growing, surface roots springing from the base of a stem that shows very little tillering. At harvest time, the majority of crops appear very 'thin'; and it comes as no surprise to learn that often the yields are only of the order of 800 to 1000 kg per hectare. Such a low farming return could not be tolerated if farm labour costs were not also low; and such yields cannot possibly pay the capital investment needed in new and better machinery. As it is, far more money is invested in harvesting machinery than in machinery for preparing and maintaining the soil. Perhaps the explanation of this lies in the fact that, on some farms, harvest time is almost the only time in the year when the owner is present to supervise agricultural operations.

The standard of soil management improves in going from north to south, but many of the above features (which relating mainly to land preparation and wheat cropping) may still be observed as far south as Osorno Province. With this type of soil management, it is remarkable that wheat growing is considered profitable; but wheat is one of the few crops that has an approximately guaranteed price, and it is also an historically important crop in Chile. But it is certainly not the crop best suited to either the trumao or the ñadi soils.

The crops best suited to both ñadi and trumao soils are unquestionably grasses and clovers, except on the volcanic alluvial soils of the plains where most soils are well adapted to arable crops. In general, arable crops should be regarded as an integral part of a rotational system, associated with the breaking up of old grassland, and as a stage in the preparation for new grass swards. Arable crops should thus be regarded as a means of making profitable use of the fertility built up during the previous years when the soil has been under pasture.

Management of the soil under pasture is usually far from good. Most farms are inadequately subdivided so that there is little effective grazing control; little is done to control or eliminate weeds that inevitably appear; control of blackberry bushes is usually only attempted by seasonal burning which often eliminates more fence posts than blackberry bushes; pastures are seldom regularly or even adequately topdressed with fertilizers; and a host of similar management practices that are virtually standard techniques for grassland farmers on similar soils in New Zealand, are dispensed with. The result is that what appears, in its first season as a promising pasture, rapidly deteriorates into a very poor sward with little sustained feeding value. In the absence of regular phosphatic top-dressing and failure to ensure efficient grazing management, clovers usually disappear from the sward at an alarming rate. Damage by grass grubs and other root-cutting insect pests is also widespread. Only a few of the farmers, mainly those in the central and southern trumao regions, can demonstrate first-class well-managed pastures, but the fact that these examples exist at all serves as an indication of what these soils can do if they are properly managed.

With regard to arable crops other than wheat, the soils are often somewhat more carefully managed, but, nevertheless, there are very frequent cases of low yields due to uneven germination caused by improperly prepared seedbeds; cases of very slow and uneven growth after germination due to the presence of lumps of grassland turf; general failure to apply adequate amounts of nitrogenous and phosphatic fertilizers; failure to check attacks by pests and diseases; and cases of crop yields diminished severely by weed competition and by uneven ripening. All of these factors are basically due to poor soil management.

The following paragraphs are more concerned with specific aspects of soil management.

2. Tillage

The comment has already been made that, in general, trumao farmers plough too late, too hurriedly and too deep. It will be evident from a study of the available chemical data presented in part IV, that in trumao soils a very large part of the natural fertility resides in the topsoil. Not only is the base status of the topsoil far higher than the subsoil, but the phosphate 'fixing' power is slightly less in the topsoil and, moreover, plants have the possibility of drawing some of their phosphate requirements from the organic-phosphate complexes of the humus system. Therefore, any technique or operation that seeks to dilute topsoil material with subsoil material will be harmful to crop growth. An additional factor is that natural topsoils are usually slightly firm whereas the subsoil immediately beneath is often extremely powdery and very friable. It is better to try and compact this latter horizon rather than stir it up and mix it through the topsoil.

Instead of using moleboard ploughs (which, in any case often scour inefficiently owing to the lack of quartz sand grains in the soil: - see Roberts, et. al., 1958 - or heavy disc ploughs, an instrument is needed that will chop up the old pasture and stir up the very surface of the soil while at the same time compacting the soil beneath. When the moisture content of the soil is right, a standard disc harrow can be used to prepare an excellent seedbed on trumao soils, but the land has to be worked several times in a criss-cross pattern and the cutting edges of the discs should be set as straightly as possible to ensure only shallow penetration. If the grass sod is very thick and tough, some preliminary treatment with a simple grass "grubber" is advisable. Any implement or technique that penetrates deeper than 15 cm is digging too deep; a cultivation depth of 10 cm with very well-chopped grassland residues is to be preferred.

After achieving the right degree of breaking-up of the old pasture sod, the tilth can be further improved by alternate light rolling and harrowing, until a very firm, smooth and even seedbed is achieved. If the land is to be left for a summer fallow, periodic strokes with a light offset disc harrow will maintain the land almost free of weeds. If the surface becomes too powdery from this treatment, the light roller can again be used. Rolling is extremely important, especially on summer fallow, to conserve the soil moisture. Soils that are rich in allophane clays need to be kept slightly moist to give best results. Any technique that reduces moisture loss helps to prevent the drying out of the soil clay, and so reduces the aggregation of the clay into silt-sized particles that are easily removed by the wind, and so slowly return to their original amorphous condition when the land is moistened by rain.

All crops, without exception, should be drilled into the soil and phosphatic fertilizers should be emplaced, either with the seed or in bands alongside, at the time of sowing. Sowing should be followed by further light rolling, especially necessary if the soil is rather dry, but this operation should not be omitted even if the soil is quite moist.

The objective in all these operations is to increase the soil consolidation; to keep within the topsoil layer; to break up and distribute the grass humus as evenly as possible, and to conserve what moisture is available in the soil. Proper respect for the tillage requirements of trumao soils will go far towards reducing crop losses due to frost-heave in winter; helps to prevent the proliferation of ground-dwelling insect pests; and reduce losses due to weed competition and to uneven ripening.

A surprising number of these observations apply equally well to ñadi soils. These soils have an initial problem of poor drainage, but in overcoming this, many farmers fall into the error of over-draining their soils; so that eventually, during the summer season, they are dealing with the equivalent of a rather acid and humus-rich kind of trumao soil, in which the chief limiting factor to production is actually a lack of moisture. It is very easy to over-drain ñadi soils.

The tillage requirements of ñadi soils are closely bound up with drainage operations, and both aspects are discussed more fully in the following section on moisture conservation, irrigation and drainage.

3. Soil moisture conservation, irrigation and drainage

Each of these three aspects of soil management are intimately concerned with the peculiar properties of allophane clay. Allophane is an amorphous colloidal substance that, when moist, can expand its envelope to embrace a relatively large volume of water, and hold much of this incorporated water against the normal pull of plants roots or surface evaporation. Under strong drying conditions, the colloid slowly loses water and shrinks in volume. Often adjacent colloidal particles shrink towards each other so that clumps of colloidal particles are formed. When thoroughly dry, these colloidal clumps have the size of fine silt and they reabsorb water very slowly. Often the soil may appear quite dry, yet under the influence of a very low night temperature water may be extruded to form long frost-pillars such as are often seen on exposed road banks in winter. When squeezed between the fingers, soil that has the apparent texture of silt or fine sand may suddenly extrude sufficient water to give a distinct "slippery" or greasy" feeling.

These physical properties become particularly important when the soils are subjected to any marked departure from their normal moisture regime: - such as occurs when normally wet soils are subjected to drainage (as in the case of the ñadi soils); or when forest soils are cleared, ploughed and sown down to arable crops; or when trumao soils are subjected to continuous irrigation. The farmer often seeks to introduce severe and abrupt changes in the soil environment, but although often at first, slow to react to the new conditions, yet when the soils do begin to change they may do so rapidly and in an undesirable manner. With allophanic soils it is very necessary that farmers curb their impatience, and develop their management technique consistently and step by step, so that abrupt, often irreversible, changes in the soil system may be minimised.

The conservation of soil moisture in well-drained trumao soils has already received mention under the head of 'tillage'. It is always an important aspect of their management, but it also has considerable significance in drained ñadi soils. It can best be achieved by maintaining the land in a consolidated condition at all times. In the northern trumao soils, the naturally light and fluffy condition of the upper horizon of the subsoil has to be gradually changed to a firm, well-packed, layer for best farming results. This poorly consolidated horizon diminishes in thickness and fluffyness in the central trumao soils, and all but disappears in the southern trumaos, but it often appears in drained ñadi soils. Two kinds of roller, light and heavy, preferably constructed of independent small segments, are essential items of farm equipment for farmers on allophanic volcanic ash soils; especially where the normal stocking rate of animals on the pastures is rather light (such as occurs on farms where inadequacy of subdivision fences prevents closely controlled stock management).

Irrigation problems on trumao soils are rather more subtle. Most of the allophanic volcanic ash soils under irrigation are derived from volcanic alluvium and are hence of somewhat more mixed origin than trumao soils from loessic or subaerial ash materials. They usually contain more quartz particles and, often, relatively less allophane clay due to admixture with other types of clay. Irrigation water may, at first, be slow to penetrate into these soils, but once the surface is moist it usually moves rather rapidly down through the profile. For this reason, the soils give their maximum production when irrigation water is applied rather frequently and in closely controlled amount. The traditional Chilean system of flooding the landscape once in a while with absurdly excessive quantities of water, may work reasonably well in some soils, but it is extremely wasteful in trumao soils and may do lasting harm. During the relatively long interval between successive floodings, the amorphous allophane tends to shrivel to form aggregates which, being slow to re-absorb water, move into the cracks and fissures in the soil when an excessive head of water is applied at the soil surface. These, in time, block the natural pores in the soil and lead to deterioration of the rooting environment. If the lower horizons of the soil are slightly compact (and this is often the case with many trumao and ñadi soils), excessive irrigation produces temporary waterlogging of the subsoil, which further affects the efficiency of the plant root system. Such a regime of alternate wetting and drying is not at all suited to allophanic volcanic ash soils (unless the land is to be used for rice cropping), and farmers who invest capital in irrigation systems for trumao soils need to be particularly careful to see that the water is applied to their land in a sensible and economical manner.

In the case of ñadi soils, Chilean farming practices seem to be mainly an adaption of practices currently in use on semi-swamp soils in North America. Comparable allophanic soils scarcely exist in the latter region (except, perhaps, in parts of the states of Oregon and Washington) and it is thus less surprising if, for lack of local study, Chilean farmers are not getting the best results from their ñadi soils.

The initial drainage operations are often carried out by digging a pattern of open field drains by hand after the land has been roughly cleared of the natural forest. These are invariably excavated down to the compact and cemented gravels which usually are found at about one metre below the soil surface. In this condition the land is used for rough pasturage for a few years, while the remainder of the trees, brushwood and stumps are gradually being cleared. Further deep lateral drains are often constructed during this period. After a number of years of hard work, the farmer has succeeded in creating an area of cleared and drained potential farmland, with soils that are dry enough to carry stock all through the rainy winter season. However, the quantity of feed from the pastures in summer is often most disappointing. On a number of farms this is certainly due to over-drained summer conditions, although it is least in evidence on farms where fertilizers are regularly used and stock management is of a high order.

The result of over-drainage of allophanic soils may be more serious than most farmers realise. Under natural conditions ñadi subsoils are continuously moist, even during the driest weeks in an abnormally dry summer season. In their natural condition, the amorphous allophane clay is probably in a continuously hydrated state and has become adjusted to that state for over a very long period. When drainage operations commence, the surface water first finds its way into the drains; and then, more slowly, subsoil layers begin to discharge into the drains. Where the drains are deep, the process is a more or less continuous one and the soils steadily dry out, except during actual rainy periods when there is some recharging of the surface layers. After a few years, water loss from the upper part of the subsoil is sufficiently advanced to allow the allophane clay to dry out (i.e. to lose water formerly held within the actual colloidal envelope of the clay particles) during the summer, and the clay shrinks greatly in size. Adjacent clay particles often aggregate together to form new particles of the size of fine silt. Once properly dry, these particles are difficult to re-wet, and when the first rain comes after a dry period they appear to move down the profile into cracks and fissures. In some soils they tend to pack and accumulate (often this occurs along the interface between two unrelated ash strata) forming a temporary silt pan which becomes an impediment to through drainage in winter. In time, the clay regains some of its power of absorbing water and behaves as a clay-enriched horizon which may function as a serious impediment to drainage and gives rise to perched watertables. Many of the farmed ñadi soils show incipient development of these silt and clay enriched horizons in the upper subsoil; and they often prevent the penetration of water into the lower subsoil during the autumn and early winter months. The lower subsoil materials become wetted by the slow, gradual, rise of the true watertable extending upwards from the compact gravelly substrate. The dry zone in the subsoil, between the upper (perched) watertable and the lower (true) watertable is eliminated only when the lower watertable level rises to connect with the perched water above.

A thoroughly dry ñadi subsoil has a most fearsome appearance (see Fig.), with fairly regular, very wide, shrinkage cracks extending from the base of the topsoil to the gravelly substratum. Soils that have dried out to this degree are never encountered under natural conditions and fortunately seldom occur on farmed land except in the lateral walls of roadside 'borrow-pits' and in very deep drains. Soils that have dried out to this condition, have very rapid drainage and there is a tendency for the subsoil pillars to collapse with the passage of subsoil water, making drain maintenance a constant worry for farmers whose soils are approaching this overdrained condition.

The aim of land development on ñadi soils should be the gradual lowering of the watertable, accompanied by gradual consolidation of the land. During these operations, the subsoils should never be allowed to become dry. It would be far better to carry out all the clearing and stumping operations on the land before drainage is attempted at all, and then, when the land is fairly clear and level, the drainage pattern should be traced lightly in the topsoil with plough or scraper before the fence lines are put in. In this state the land can be used quite well for summer pasturage, but stock may need to be taken off the land during the wettest part of the winter. The soils will usually bear heavy machinery in the summer, and at this time, successive discing and operation of rolling and, finally, sowing of pasture grasses and clovers can be carried out, - accompanied always by application of fertilizers.

After some years in this condition, consolidation of the topsoil and upper subsoils will make necessary the deepening of the drains. These can be deepened by machinery or by hand, but in this stage of the development operations they should not extend all the way down to the compact substratum, except in the case of very shallow ñadi soils. It should be remembered that this substratum is usually not a smooth sheet but has its own slightly undulating surface, independent of the undulations of the soil surface. As a result certain areas are naturally 'ponded' areas which are difficult to drain. In some ñadi soils where this feature is common, the only solution is to make a topographic map of the two surfaces (the substratum and the actual soil surface) and plan underground channel-ways to relieve the accumulation of water in the higher ponded areas. To do this explosives may be required, but in all cases the excavated channels should be filled with brushwood and the soil replaced and levelled across the drain.

With the establishment of this second stage in the drainage system the land is ready for intensive farming. Additional fences can now be installed and the land can be worked in very much the same manner as the trumao soils, with emphasis on surface working of the soil and on occasional rolling to maintain consolidation; with strong emphasis on the regular application of fertilizers, placed near the seed in the case of phosphatic fertilizers; and with careful stock management to control weed invasion of pastures. The chief difference between soil management of properly drained ñadi soils and the naturally well-drained trumao soils lies in the need for greater care in selecting the right soil moisture conditions for tillage operations. This is especially important in the case of ñadi soils.

4. Soil conservation

Soil conservation measures are not widely adopted by farmers on trumao soils. In part this is due to the excellent natural tilth of the soils which supports abuse far better than many of the associated soils in the local soil assemblage, and in part it is due to lack of understanding of the subtle action of soil erosion. The Soil Conservation Service of the Ministry of Agriculture has from time to time amply demonstrated simple systems of soil conservation suited to these soils, but the demonstrations have often had all too little impact on the subsequent practices of the local farmers.

Two kinds of erosion are prevalent: wind erosion of topsoil materials from ploughed fields, and sheet and rill erosion from cultivate sloping land. The latter class of erosion occurs even on very gentle slopes by virtue of the fact that sun-dried topsoils absorbs the water from a heavy shower rather slowly, and during the onset of rain there is at first a considerable volume of surface run-off which carries away important amounts of topsoil material. Deeper kinds of erosion (e.g. gulleying and slipping) are less common, except on steepland soils in the Andean ranges where truly spectacular slips and debris-avalanches are often widespread on land cleared for farming (Wright and Mella, 1961). In the Province of Aisén, where the ash mantle on steep slopes rests uneasily on un-weathered underlying rock, any disturbance of the forest root net-work may bring down millions of tons of soil, rocks and trees on the hapless valley settlements, (Vogt, 1948, p. 188).
Thus erosion is far from being absent in trumao soils, as many farmers claim. Erosion may also appear, in the form of rill erosion, in ñadi soils on very gently sloping land. The soil conservation measures needed are generally fairly simple ones. In the case of the spectacular erosion in the Andes, obviously the steep hillsides should not be deforested and the valley farmers should be under serious threat of confiscation of land if they do not observe proper fire-control methods when burning off invading second-growth vegetation. On the landscapes of farmable but rather sloping relief, contour ploughing and working the land along the contour should be adopted more generally. This applies particularly to the farmers of Chiloé, where the more fertile soils are mainly to be found on strongly rolling to somewhat hilly landforms and where the practice is, almost without exception, the growing of row crops (mainly potatoes) up and down slopes which are often in excess of 20°. Undoubtedly, in Chiloé, this custom is related to securing maximum drainage conditions to combat the high precipitation of the region, yet the general loss of topsoil is so serious that a considerable area of land has now gone out of cultivation, and many areas are showing a marked decline in productivity. Contour ploughing and contour cultivation is to some measure practised in the Osorno, Cautín and Llanquihue Provinces, but it is by no means as general adopted as it should be. This valuable technique is virtually ignored by the latifundistas of the northern trumao region.

For trumao soils, soil conservation is practically synonymous with moisture conservation, and the tillage practice of consolidation (by rolling) also help to diminish losses from wind erosion. On most trumao (and many ñadi) soils, the forest was cleared without giving thought to leaving shelter-belts across the line of the prevailing winds. To-day, winds sweep unchecked across the land, picking up the deep-ploughed, very loose and powdery topsoils which are especially vulnerable when the ground is bare before sowing, and again when the stubble is burned after harvest. This dust (the 'trumao' of the Araucanian) piles up in dunes in the sunken roads and along hedgerows, and it represents some of the best of the soil materials, stripped from the farmer's field.

5. Use of fertilizers

The proper use of fertilizers is an essential part of farming on trumao and ñadi soils. As indicated at many points in this report, the phosphate 'fixing' power of the allophanic volcanic ash soils is exceedingly high, and is complicated by a phenomenon that appears to be related to aluminium toxicity. For some crops (e.g. sugar-beet) almost no growth at all can be obtained unless some phosphate is supplied; and reasonable economic crop yields require that the phosphate be placed in the soil in close proximity to the seed. In the absence of phosphatic fertilizers, with aluminium-sensitive crops, there is little growth beyond the seedling stage: the young plants survive for a while on the food supply in their cotyledons but when only a few centimetres high, growth gradually stops and the plants become more and more yellow; subsequently showing spreading necrotic patches until all plants die. This phenomenon is thought to be due to aluminium toxicity and the phenomenon is still under active investigation (E. Letelier, pers.com., 1963). It is of great importance to the recently established sugar-beet industry that this problem be thoroughly understood.

The problem of phosphate fixation in these soils appears to be somewhat similar to that explored in some detail in New Zealand (e.g. Saunders, 1956, 1959; Jackman, 1955) and in many other countries. The total quantity of phosphate in these soils may be quite high, but by far the greater part is incorporated in organic compunds or is bound to the anion exchange surfaces either directly or through alumina and iron. In none of these forms is the phosphate readily available to plant roots. Schenkel (pers. com., 1961) has shown that in many trumao soils up to 90% of the added phosphate changes to forms that are difficult to extract. In New Zealand, on some volcanic ash topsoils, up to 60% of the soil phosphate may be present as organic phosphate which becomes available to plants only at a very slow rate. To offset this intrinsic soil property, farmers need to pay special attention to regular phosphatic topdressing, using relatively large amounts and methods that place the phosphate in the soil near the plant roots. If simple phosphate fixation were the only limitation to fertility in these soils, very finely ground very soluble forms of phosphate would be expected to 'fix' most readily in the soil, whereas coarsely ground or artificially 'pelleted' forms of phosphate would be expected to have the more lasting effect in plant nutrition on these soils. The presence of a toxicity factor that appear to be associated with aluminium introduces a complicating element, for the best and quickest way to overcome an aluminium toxicity is likely to be the application of some highly soluble form of phosphate, or even a solution of phosphate. For this reason, farming opinion is at present divided between those who claim to get the best results from more soluble forms of phosphate, and those favouring slowly-soluble forms. This is an important field for future research.

Many crops sown on trumao and ñadi soils show signs of nitrogen deficiency during their early period of growth, and most crops give a good response to added nitrogen. It is not yet legal to use manufactured ammonium nitrogen fertilizer in place of sodium nitrate in Chile, and there is little doubt that farmers on trumao and ñadi soils are penalised by this law. Experience overseas has shown that, on allophanic soils, ammonium nitrate is the far more satisfactory and economic fertilizer to use. In part, the need for nitrogen arises from the turfy nature of many seedbeds, and this latter feature is often responsible for the patch growth of the crops; but nitrogen is generally somewhat deficient in almost all trumao and ñadi soils, - as witness the marked improvement in crop growth in areas formerly occupied by old haystack accumulations, and by the much greener pasture growing at the site of animal droppings in grazed pastures.

The application of lime to trumao and ñadi soils is somewhat controversial. On the basis of pH, most soils range from weakly to quite strongly acid, and exchangeable calcium in the cation exchange complex is often low. On this evidence alone, one would imagine that these soils would be responsive to liming, especially if applied in conjunction with adequate amounts of reverted superphosphate, since in this way some of the phosphate 'fixing' power of the soil might be neutralised. Results from field trials have, however, proved inconclusive; except possibly those conducted near the southern limits of the trumao range, where many farmers consider that liming is definitely a paying proposition. There are several possible reasons for this, all with relationship to alumina and aluminous colloids. For example, it has recently been shown (Fox, de Datta and Sherman, 1962) that under the tropical conditions of Hawaii, one of the important reactions of lime in acid soils appears to be the replacement of exchangeable aluminium in the exchange complex by calcium, with the consequent formation of aluminium hydroxide. In New Zealand, it is the custom to apply most of the lime (with phosphate) to the pastures, and not directly to the ploughed soil near the time of sowing; possibly this is the reason why liming is usually regarded as beneficial to farming under New Zealand conditions, yet its value is still doubtful in Chile. Also, it must be remembered that most Chilean allophanic volcanic ash soils are rather less weathered than their New Zealand counterparts, and that there is greater possibility of interaction between lime and the initial (ionic) products of the weathering of volcanic glass under Chilean conditions. Very large dressings of lime may be needed in Chile to get the same magnitude of response as in New Zealand, and also the time of application of the lime may need to be quite different. The placement of lime by drilling it into the soil simultaneously with seeding is a new technique that might be worth trial in Chile.

Few farmers regularly apply potassic fertilizers to their soils, and careful experiments (Letelier, pers. com.) show that in most trumao soils and many ñadi soils there is no economic response to added potash. In general, this agrees with chemical data which indicate that adequate levels of exchangeable potassium are normally present in the soils. It is also true that there are a few soils that have low exchangeable potash levels yet give no measureable potash responses. In view of the high cost of the imported potassic fertilizers, their widespread use should not be encouraged until further experimental data are available.

With regard to theoretical potash requirements on these soils, it is interesting to note that the parent ash seldom contains layer-type silicates that could weathe. to form platy illite-type clay minerals (Fieldes and Swindale, ibid, 1954) which can 'fix' potassium in difficulty available forms. Hence, when the exchangeable potassium of the cation exchange complex is exhausted, the only source of fresh potassium will be from the weathering of primary minerals; and when most of these are exhausted (as will eventually occur in the more strongly weathering environmental zone where there is no fresh addition of volcanic ash to the soil surface) indications of potash deficiency may appear. This may be occurring in the case of some soils in Chiloé Island at the present time. Potash deficiency symptoms were recently noted in potato crops. The extension of sugar-beet cultivation to Chiloé Island may bring this possible deficiency into greater prominence.

Much the same comment may be made concerning the use of magnesium and of the minor elements on trumao and ñadi soils. In the few trials that have been made, no marked or consistent responses have been noted, apart from a very marked but irregular response to sulphur that has appeared in some soils. Sulphur, in the form of sulphate, gives excellent responses in some seasons (more especially with clovers), but the effect cannot be guaranteed in subsequent seasons. There clearly is some relationship between this response and seasonal microbiological activity under varying moisture conditions. Since soil microbiology is an almost unexplored branch of soil science in Chile, the validity of using sulphur compounds as soil amendments must await the development of microbiological research in the territory.

Boron has been widely used as a soil amendment in the region of the southern trumao and in ñadi soils; - to such an extent that it is now difficult to be sure of the original boron status of many agricultural soils in the region. However, boron deficiency symptoms seldom appear in sugar-beet crops, and it is arguable to what extent this is caused by residual accumulation of boron in the soil resulting from the widespread use of boron in former years and how much is due to the presence of adequate levels of boron in the soil in nature. Trials with boron are needed on strictly 'virgin' soils to elucidate this point.

Very little spectrographic work has been done on Chilean soils, and spectroscopic equipment in the country appears to be used mainly for demonstrations for teaching purposes. There is no clear picture of the minor element status of allophanic volcanic ash soils in comparison with that of other Chilean soils; nor in comparison with similar soils in other countries. Some recent work was carried out on allophanic volcanic soils from Easter Island (Wells, pers. com., 1962; also Díaz and Wright, in press) that show these soils to be of approximately equivalent minor element status to comparable soils in New Zealand and the Pacific Islands.

6. Crops and cropping systems

This aspect of soil management has already been partially covered in the introductory paragraphs of this section. In general, established cropping systems scarcely exist on these soils in Chile. Wheat is often sown when an immediate cash return is needed, irrespective of any planned cropping rotational system, and irrespective of the condition of the pastures that have to be ploughed up. Crops other than wheat are likewise sown, more on the basis of the economic prospects of the current market, or because certain farmers found the crop highly profitable in the previous year, than as part of planned management practice. This leads to alarming fluctuations in volume of produce: alternating scarcities and excesses of production that, in the end, leave many farmers discouraged and poorer despite their best endeavours. A year of high prices for a particular crop is almost invariably followed by a year of excess production and very low prices.

In Chile, it is therefore doubtful whether, outside of the field of animal husbandry, planned cropping systems can hope to emerge without the stimulus of guaranteed prices and assured markets. Only in the comparatively new endeavour of sugar-beet growing, where there is an assured market and an established scale purchasing price, are planned arable cropping systems beginning to emerge.

7. Soil management problems

Many soil management problems have been referred to in earlier paragraphs, and this is perhaps a suitable place to summarise them and restate their relationship to the soil properties that are inherent in all allophanic volcanic ash soils.

These soils possess several special blessings for the farmer. The floculated allophane clays ensure friability and excellent tilth; and as a consequence the soils may be worked over a wide range of soil moisture conditions. Even a bad farmer cannot fail to benefit from these properties. There are no management problems in this aspect of the soils.

However, friability and good tilth are accompanied by excessive looseness and fluffyness in many trumao soils, and these properties do present management problems which should be countered by shallow tillage and regular rolling of the soil to aid compaction.

Compaction itself is an aid to soil moisture conservation on trumao soils. Since the northern trumao soils (and to some extent also the central trumao soils) are liable to acute summer dryness, the use of implements to compact the topsoil and upper subsoil horizons has a double purpose in soil management.

Drainage problems arise mainly in the case of ñadi soils and the few trumao soils derived from volcanic alluvium that are subjected to excessive irrigation. In the case of ñadi soils, drainage ditches should not be made deep at the outset and an attempt should be made to keep the soil reasonably compact and moist during the driest weeks of summer to prevent subsoil fissuring and the subsequent development of drainage-impedence layers close to the surface. Drainage in ñadi land should be a gradually deepening process in place of the present system of trying to create a sudden and major change in the drainage regime at the outset of development operations.

Lack of interest in soil conservation measures, no matter how simple is a management problem on a rather larger scale. Most farmers on trumao and ñadi soils consider that these matters are of minor significance alongside their more obvious soil fertility troubles. The problem nevertheless exist, and its bad effects will inevitably be cumulative.

The management problem that most concerns the majority of farmers is 'what fertilizers should be used'. Interest often extends to the purchase of a few sacks of fertilizer, but the contents are usually disseminated over as wide an area as possible, in many cases, with little real faith in the result. There is frequently no visible result. With amounts of phosphatic fertilizer equivalent to only about 50 units per hectare, broadcast on the soil surface, very little of the added phosphate will be available for plant nutrition. Fertilizer use must be taken seriously, must be carried out following a pre-arranged plan, applied in the right way to the soil and crops in the right condition, - else, money is simply being thrown away. With trumao and ñadi soils, the financial outlay for fertilizers must inevitably be large, and a sufficient quantity needs to be purchased in advance to ensure that there will be adequate fertilizer on hand when the time comes to use it. All fertilizers need to be stored with care and protected from moisture. At the time of application, the fertilizer should be spread in fairly precise amounts, with suitable machinery to ensure proper distribution. Under these conditions the use of fertilizers, more especially phosphatic fertilizers, will pay a handsome divident on trumao and ñadi soils. It is most emphatically not the type of agricultural operation that can be safely left to a partly trained farm foreman. The two chief items of agricultural waste in Chile are misuse of water resources and fertilizer purchases.

The final aspect of management is one that presents a many sided problem and relates to the lack of farm planning or lack of adhesion to carefully prepared farm plans. This arises mainly from the grave uncertainty of farming in Chile. The traditional latifundista suffers less from this uncertainty than the enthusiastic, well-meaning and hard-working small farmer. The former has his broad plan of operations, based on a small annual outlay and small yields from a large number of hectares on a big estate: he works on the principle that even small yields gathered over a big area represent a tidy farm income. The smaller farmer fights harder to make his land produce, perhaps even adopts a long-range farming programme, but he is not sufficiently buffered against the sharp winds of economic change, and, time and time again, in an effort to remain solvent he is forced to adopt some expedient that makes a mock of his long-range programme. For various reasons, the winds of economic change can be very sharp indeed in Chile, - a country where financial credit is not easy to come by and rates of interest are exceedingly high, - so that the very farmers who should be the backbone of the agricultural system are exceedingly vulnerable. In part, this factor goes far towards accounting for the phenomenally high rate of turn over of agricultural properties in Chile.

c) Soil productivity

There is no escape from the fact that the soil productivity, as measured by average yields from trumao soils and some ñadi soils, is deplorably low. In the region of the northern trumao soils, even in good years, the average wheat yield may fall below 100 kg per hectare. On better managed farms, in good seasons, the yield may rise to over 3000 kg per hectare; and even this is probably far short of what these soils could produce if properly handled. The range between the poorest and best yields in any district are amazingly wide and reflect the great range in the quality of soil management, as much as anything.

Grassland production again probably falls far short of the true potential of the soils. Over many square kilometres the carrying capacity is as low as 1 sheep unit per hectare (0.2 cattle beasts per hectare), whereas most of the trumao soils of the central and southern region could readily be brought into a condition where they could support 2 cattle beasts per hectare. In some cases this figure might be doubled with precise farm planning and careful soil management. A ten-fold increase in total productivity might not be possible on all farms, but the production figures from some of the better farms in the Cautín and Osorno regions show that this increase is within the realms of possibility.

Since poor soil management lies at the bottom of most production failures with these soils, it is as well to stress that attention to only one or two aspects of soil management to the exclusion of the rest, only shifts the limiting factors along. If one intends to invest in equipment more suited to the soil conditions, there must also be enough capital left over to make the necessary fertilizer purchases, to buy the chemicals to control any sudden outbreaks of insect pests, and each step in the chain of soil management has to be similarly covered. In reality, these would appear not to be soils suited for farmers with strictly limited resources. Yet in New Zealand considerable areas of the volcanic ash soils have been brought in by just this type of farmers; - by persons with very limited capital resources, but backed by liberal credit at low rates of interest. The job can be done by the small farmer but the financial environment must be prepared beforehand.

d) <u>Engineering uses and problems</u>

Trumao and ñadi soil materials have few engineering uses, but many engineering problems.

Both the trumao soils and the drained ñadi soils have very low apparent density, high field capacity moisture content, and high water-holding capacity in their normal condition; yet under stress they can change their nature very drastically as was demonstrated during the earthquake of May, 1960.

With regard to the volume weight of these soils, a layer of dry soil, one hectare in area and approximately 7.5 cm in depth, weighs only about 400,000 kg, which is rather less than half the weight of an equivalent volume of most other Chilean soils. The soil material is, moreover, highly porous in its natural condition, and when thoroughly wet these pores may hold a considerable amount of water. There is thus the possibility of great difference in volume weight between wet and dry soils.

In general, when thoroughly dry, trumao and ñadi soil materials behave rather like very fine sand or silt. They usually resist the entry of water at first, but when thoroughly moist they behave like the clay that they really are. Under proper treatment they can be dispersed completely to give very high figures for the clay fraction.

During the earthquake of 1960, it was apparent that materials rich in allophane had been used for numerous engineering purposes where they should not have been used. The most serious examples occurred where allophane clay fill had been employed to level landscape irregularities in preparing house foundations, and used to build earth ramps at the approaches to bridges and railway overpasses. Most of the bridges themselves and the greater part of the cement highway system, were unaffected by the seismic waves, but large sector of the road system were intransitable immediately after the earthquake owing to the collapse of the earth ramps leading to the bridges. Every case of serious damage of this sort proved to have been due to the employment of trumao or ñadi soil material scraped off the surface of the surrounding landscape, (see also Wright, 1961, p. 144). These materials when are slightly dry, appear to be highly suited as filling material; but they are exceedingly treacherous when moist and cannot carry a heavy load in this condition. Under the impact of seismic waves, the clays appear to exuded moisture in sufficient quantities to become almost liquid; many buildings actually slid along on surfaces lubricated by allophane.

The effects of the earthquake on the allophane clays was not confined to the towns and cities and to the main communication links, but was also mainly responsible for many catastrophic landslides that occurred in parts of the Andean cordillera (Wright and Mella, 1960, 1963). Several small agricultural settlements, and their inhabitants, were overwhelmed by the landslides that were triggered by internal changes in the allophane clays occurring in some layers of the volcanic ash mantle that lie thickly on many of the steep slopes of the Andean ranges.

Because the properties of allophane are liable to sudden and abrupt change, the trumao and ñadi soils have scarcely any engineering uses; and for the same reason they present a multiplicity of engineering problems.

PART III

FARMING POTENTIALITIES OF CHILEAN ALLOPHANIC VOLCANIC ASH SOILS

a) Introduction

In the preceding parts of this report, various aspects of the soil properties have been related to environmental factors, to present land use patterns, and to problems of management and productivity. In part III the problem will be looked at from the other aspect, - to explore what the farmer on these soils can do in the way of serious planning to ensure that he gets a better return for his efforts. This virtually amounts to setting up a 'blue-prints' for farming operations, designed within the present and foreseeable economic framework of the Nation, adapted for the farmer without unlimited capital resources, and suited to fairly representative kinds of allophanic volcanic ash soil.

Obviously, one common plan cannot be devised to suit all the wide range of landscape, of climatic conditions, and soil variations that occur within the full range of these soils in Chile, but an example can be drawn up for a particular set of conditions that have quite widespread application in a particular region; and situations where the suggested procedures are not applicable can be indicated. Only in this way can emphasis be drawn to the point mentioned earlier: that soil management practices achieve their desired effect only when they are integrated and followed according to a predetermined management programme.

b) Suggested farm management programme for medium-sized property on trumao soils in Bío-Bío, Malleco or Ñuble Provinces

Farm management planning can only be carried out with reference to some specific property. The example given below was selected because many of the conditions on the property are common to many other properties in the northern region of the Trumao soils, and because a farm management plan had previously been prepared for the owner, by Sr. Guillermo Numhauser, who has very kindly collaborated in the preparation of this section of the report. The farming 'blue-print' presented below would need modification before it could be applied to other properties in the region, but many of the general principles on which the plan is founded do have wide application throughout the northern Trumao soil region.

The location and original condition of the property will be described first; followed by a brief description of the various aspects requiring attention; leading to a skeleton outline of the general plan adopted for the property; with, finally, a summary of the capital and credit needed under the plan during the first few years. It should be noted, again, that attention to only one or several of the improvements needed under the plan will not bring the desired results: all aspects of the programme must be accepted and deal with faithfully, else much of the money spent on the improvement of the property may well be lost.

1) Location and nature of the farm in its original state

The property is situated some distance inland from the town of Santa Bárbara, the last point on a railway leading to Los Angeles and the main road and rail arteries running north and south. It is located in the foothills of the Andean ranges, containing both undulating, rolling and hilly land, and covering an area of 4500 hectares; which is a common size of property in the region.

Practically all the soils on the property belong to the Santa Bárbara series (Santa Bárbara facies), varying considerably in depth according to the land slope. The shallowest soils are on the hilly sectors, where there are also some outcrops of andesitic rock. The soils have no serious inherent limitations that would prevent their being utilised for agriculture. In part the relief is undulating to rolling (2% to 8% slopes), and much of this land has had a long history of wheat cropping. Locally, gulley erosion has made its appearance as a result of complete neglect of elementary soil erosion practices.

In addition to wheat growing, some sheep and cattle have been maintained on the property, but were regarded as a minor side of farming, - of much less importance than wheat cropping.

Of the 4500 hectares, 400 hectares consist of land of gentle relief, more or less completely cleared of the original forest and in regular wheat cultivation on a two year cropping cycle followed by several years fallow; 500 hectares consist of similar land incompletely cleared of forest debris and used mainly for rough grazing; and 3600 hectares are hilly land with remnants of the original forest, patches of regenerating forest and scrub, and occasional patches of volunteer pasture and weed plants.

Former management practices included the aforementioned wheat cropping to excess; hand broadcasting of wheat seed; no employment of fertilizers whatsoever; deep, irregular ploughing using a single furrow implement and employing bullocks; generally late and hurried breaking of the fallow; very bad seedbed preparation; and no special attempt to counter the invasion of weeds or insect pests. The rough grazing land, and the volunteer pastures that appeared between wheat crops, provided poor grazing for some 400 head of livestock, which included sheep, goats, and cattle. The latter were purchased at 1.1/2 to 2 years of age, maintained on the farm for about 10 months, and then sold: usually about 80 cattle beasts would be 'fattened' in each year. No vaccination or anti-parasitic routines were followed, yet, despite this, livestock mortality was low, calving rates good, and by the standards of the region the animals were of above average quality and marketed well. In the case of the sheep, lambs weaned at 4 to 5 months weighed on the average 35-40 kilogrammes. The cattle, without supplementary feed, showed a reasonable weight increase during the period of their stay on the farm.

The property is amply supplied with a resident labour force and abundant unskilled manpower is available in the surrounding districts. Markets are readily accessible, and the nearby centres of Los Angeles, Chillán and Concepción ensure that this is a high demand for farm produce.

No part of the farm has irrigation but it would not be difficult to arrange irrigation for much of the land of low relief. The capital outlay needed for this would undoubtedly be high, and thus would not be advisable until the property was brought into a higher level of production. Rainfall in the area amounts to a mean annual total of 1643 mm, of which only 7% falls in summer, 18% in the spring, 29% in the autumn and 46% in winter.

Since the history of wheat yields over the past ten years has been both low and tending to show an overall decrease annually (except in exceptionally wet years), and since the former history of livestock on the property has been encouraging, it was decided to plan the development of the property on the basis of dryland livestock farming, with strong emphasis on sheep breeding. Wheat cropping would be relegated to a minor role and used for the dual purposes of breaking up old pastures and re-seeding new ones. Before such a change could be undertaken, many of the existing features of the property would need modification.

2) Modification of existing features

Based on a plan prepared showing the existing resources and layout of the farm, the following aspects were scheduled for attention:

i) Subdivision of fields

Size and shape of the fields are of vital importance in livestock farming on improved pastures. The existing fences were in only fair condition and most had been laid out following the piecemeal clearance of the forest without regard to soils or topography. A few of the existing fields could serve in the new scheme, but the great majority needed re-designing, taking into account as need for a new system of water reticulation to supply livestock.

ii) Pasture improvement

This would be based on the sowing of grass and legume seed simultaneously with wheat. A start was planned using the fields that did not need re-designing; making use of this opportunity to experiment with various combinations of seeds and fertilizers.

iii) Internal access routes

Existing farm roads were deeply incised in the landscape owing to wind erosion of the bare earth, and owing to the action of surface water in places where the roads were acting as drains during winter. Internal access routes should be planned with some regard for topography, and, in the case of powdery Trumao soils, should either be surfaced with gravel or maintained under a permanent grass cover from the outset. The obliteration of part of the former farm road system (a major undertaking that would require the employment of a bull-dozer) and the relocation of an adequate number of access routes received high priority in the planning programme. It was planned that these access routes would be permanently grassed, either with the natural 'chépica' of the region or some better, introduced, grass; and that the original establishment of this cover would require both nitrogen and phosphate to get a rapid coverage in a single season. To preserve this road pasture, a change from iron-tyred wheels to rubber wheels on farm carts used in carrying produce was planned.

iv) Shelter-belts

Existing shelter and shade were spaced quite haphazardly, being mainly trees and clumps of shrubs accidentally left during the original land clearing operations. Selection of shade trees and planting of specific shade trees is important considering the hot, dry summer of the region. Even more important is the planting of shelter belts suitably aligned to deflect the strong south-western winds of the region. For reasons of fencing management, it is advisable to locate the shelter belt trees well within the field and not along the fence boundary.

v) Land cleaning and additional forest clearance

Much of the old permanent grazing land was foul with blackberry and native shrub invaders. Part of this land was scheduled for immediate cleaning; and the rest planned for clearing at a regular rate each year. No large trees were involved, and it was estimated that this job could be done with the regular farm equipment.

vi) Reafforestation

The large hilly section of the property was regarded as having only a very limited agricultural use owing to the higher cost of establishing permanent pastures, and the even greater difficulty in managing these pastures properly. Since it was apparent that the hilly land would not be required in the scheme during the initial years, a large part of the hilly land was set apart for planting in quick-growing Pinus insignis, and suitably wide fire-breaks assigned to protect these future forests.

vii) Drainage

Since the overall drainage properties of the Trumao soil is good to excellent, drains were regarded as being required only as a means of erosion control in places where excess surface water gathered at the foot of some of the steeper slopes. In such situations, a certain amount of construction of special erosion control measures (banks, terraces, lined canals, etc.) would be necessary, but the greater part of the farmland was not in need of field drains.

viii) Erosion control

In addition to the measures noted above, it was clearly necessary to train the farm labour in the observation of such elementary erosion control measures as ploughing along the contour, use of light and heavy rollers to give the soil consolidation, etc. Although not spectacular in effect, such simple practices are most important in these light and fluffy Trumao soils. It was anticipated that the local preference for burning wheat stubble would cease with the new practice of sowing pasture seed with the wheat crop.

ix) Selection of farm machinery

On the basis of experience accumulated over the years in the management of these soils, light machinery only was recommended, apart from one heavy roller, and a medium-weight wheel tractor (45-55 HP) equipped with a hydraulic system and wide wheels. For cultivation, an offset light harrow with an exact depth-of-penetration control. With such an implement, there would be less danger of accidental deep cultivation in the hands of an unskilled operator. Flexible teeth on this implement would be an additional advantage. For weed control and similar operations, only superficial working of the soil was anticipated. For renovating pastures, a chisel-point harrow with seedbox attachment was contemplated; and for normal sowing down of wheat and pasture seed, a normal seeder with fertilizer attachment was recommended. To complete the major machinery requirements a light and heavy roller were recommended (a 'crow-foot packer', if available). The remainder would be standard minor farm equipment.

x) Farm buildings

It was estimated that the existing farm buildings could serve during the early years of development, apart from the provision of a concrete floor in one building for storing fertilizer.

xi) Use and management of water

There are sufficient streams and springs on the property to provide water for reticulation by pipes to the various fields. It was recommended that permanent concrete drinking troughs be installed as the fields were subdivided, and each provided with a simple automatic water control system. As mentioned earlier, water for irrigation would require considerable extra planning, including farm catchment dams, canals, etc., and this was not contemplated until the property was showing a consistent annual profit.

xii) Management of pastures

For effective control of stock grazing on the new pastures, it was anticipated that electric fencing would be essential. Permanent post and wire fencing, using locally made concrete fenceposts, would outline the main fields, and serve as supports for temporary electric fences needed to further subdivide the grazing.

xiii) Labour

In place of an over-abundance of unskilled labour, it was recommended that an on-the-farm training scheme be instituted, using the brightest of the younger labourers available.

xiv) Control of weeds and pests

At the outset, it was anticipated that some use of herbicides and pesticides would be necessary. Much of the weed growth can be suppressed by timely cultivation before sowing, and by regularly topping uneven pastures with a mower, but weeds appearing in growing wheat and certain small but vigorous pastures weeds require the use of herbicides. In the case of pests, Trumao soils are especially prone to develop colonies of grass-grubs and other ground dwelling insects. Some of these can be attacked in the pasture, but a more effective method is to apply DDT in the soil at the time of sowing down the pastures.

3) General plan of development

In the first year the area sown to wheat would increase from 40 hectares to 100 hectares on the cleared land, and a further 60 hectares of wheat would be sown on land cleaned up out of the 500 hectares of rough permanent pasture that still has surface logs etc. This would give 160 has. of new pastureland at the end of the first season. In addition 40 hectares of grass and clover for seed production would be sown in the first year. During the first year the number of rams would be increased from 8 to 30, and sheep from 270 to 1450. By the end of the first season, additional feed to the extent of about 5000 sheep units per month would be needed, but this is unavoidable if the herd is to be built up to a level adequate to make maximum use of the grazing coming available in the second year (see table 1).

A great deal depends upon the correct selection of the pasture seed mixture. Initially, only certified seed should be employed. The basis of the sward should be annual and perennial clovers, with at least two species of pasture grasses (one of them a deep-rooting type). Moreover, the seed needs modifying in certain of the farm soils to suit specific ecological conditions, and should be further modified in the case of areas sown down for hay, silage, or permanent grassland. Normally, the main area of pasture is intended to be managed on a long-rotation system, with renovation about once in every six years.

The pasture 'cover-crop', wheat, is sown normally at 110 kg/ha. In the case of areas covered with the main soil type of the farm, the wheat will be sown down with 3 kg/ha 'Tallarook' subterranean clover seed; 3 kg/ha 'Mt. Barker' subterranean clover; 1/2 kg New Zealand white clover; 1 kg/ha Wimmera rye grass and 6 kg/ha Orchard grass (Cocksfoot). For shallower soils on more strongly rolling topography, this mixture should be modified as follows: Tallarook, Mt. Barker, and New Zealand white clovers as before, but the main grass species should be Alta Fescue at about 6 kg/ha. For the small area of improved pasture on the hilly land, clover seed as before but 2 kg/ha. Wimmera rye grass seed with 4 kg/ha English rye grass seed. On the small fields of the flattish 'bottomland' where moisture conditions are better, 8 kg/ha of red clover, 1 kg/ha of New Zealand white clover and 6 kg/ha of short-rotation rye grass are recommended. In every year after the first, a small area (up to 10 ha.) should be sown down especially to provide hay, silage and emergency winter feed. For these the seed mixtures suitable to local conditions are: (1) Crimson clover, 'Dixie strain', at 15 kg/ha with Wimmera rye grass at 4 kg/ha; (2) Vetch at 60 kg/ha with oats at 60 kg/ha; and (3) Alfalfa at 10 kg/ha with orchard grass at 4 kg/ha. The use of New Zealand white clover and of alfalfa on the farm are somewhat experimental since these varieties are not widely known in the region.

All seed should be drilled into a well-prepared seedbed, together with an adequate amount of fertilizer. The latter should be drilled in bands alongside the seed. At least 400 kg/ha of superphosphate should be applied at the time of sowing, and nitrogen should be applied to the growing crop at rates not less than 150 kg/ha (either as a single, or as several applications) in the form of potassic salitre (the best of the limited range of inorganic nitrogen fertilizers available in Chile). The phosphate can either be a coarse form of superphosphate, or, better, as a mixture of a very soluble form of phosphate and a more slowly soluble form. Minor elements are generally not needed on these soils, and some, like sulphur, gives erratic responses that appear to be related to seasonal climatic condition and the microbiological activity in the soil. If minor element deficiencies appear, it is often more economical to feed these to the livestock in the form of a stock lick, and reap the subsequent benefit when they are returned to the soil in an organic form. After harvesting of the wheat, the stubble will assist the growth of the young pasture and will help to minimise wind erosion. The initial grazing should be carefully controlled, kept very light, and care should be taken to see that the animals do not selectively eliminate all the clovers.

<u>In the second year</u> the area under wheat can be reduced to its future constant level of 125 ha, half being sown on the clear land and half on land which has to be cleared to logs and stumps etc. During the first year, the grazing deficiency had to be made up by buying in extra feed and by using some 440 ha of rough hillside grazing, but, starting with the second year, the need of hillside grazing will steadily diminish, until by the fifth year, not more than 140 ha of this rough pasturage need be regularly employed. The first of the stands for seed production can be established in the first year. Since grass and clover seed are in very short supply in Chile, it is worthwhile making pasture seed production a regular feature of the farm operations. Some 60 ha are planned to be set aside for this purpose in the second year. Also set aside, is about 10 ha of land of easy relief to be used for growing extra winter feed. In addition to the fields closed early in the season to provide hay and silage, specific fodder crops like rape, choumollier, sudan grass, kohlrabi and alfalfa can be sown to see which are likely to become the main type of crop best suited for this purpose on the farm. Starting from the 1000 breeding ewes and 30 rams purchased in the first year, the flock will have increased by some 450 ewe lambs and the same number of hoggets by the end of the first year. The latter will be sold in the autumn of the second year, but lambing will have increased the

total flock by a further 872 head by the end of the second year. In addition, during the year, some 100 head of steers can be bought in, fattened and sold. These cattle are exceedingly useful for maintaining a closer control of pastures, since they eat tall growing plants that are often avoided by the closer-grazing sheep: an adequate number of cattle should be a part of every sheep farmers pasture management equipment in this region of Chile. At this stage in the development programme, the farm should consist of 160 ha of improved, high-producing pastures; 125 ha of wheat with new pasture coming in for the next season; 40 ha of pasture exclusively grown for seed production; 10 ha of winter feed crops and pastures for hay or silage; 195 ha of unimproved pastures on land of easy relief, and 320 ha of hillside rough grazing.

In subsequent years, the same general pattern of development should be followed (refer, table 1), until by the end of the fifth year a permanent farm pattern should have emerged, in which there will be an annual area of 125 ha ploughed up and sown down to wheat and new pasture; some 635 ha of improved pastures in various stages of growth; 100 ha of seed production pasture; some 40 ha reserved for winter feed production; 140 acres of permanent pasture of the more strongly rolling land, and 100 ha of permanent hill pasture in reserve. By the end of the fifth year, the farm should be carrying a permanent flock of over 4000 sheep, with an annual sale of over 100 hoggets, and an annual wool production amounting nearly to 10,000 kg; in addition, some 500 head of steers can be fattened and sold each year. If the pasture management plan is faithfully followed, there should be a comfortable excess of grazing available each season, allowing the buying in of more stock if desired.

Healthy livestock are vital to the success of this plan. It would be advisable to initiate a systematic routine check on livestock health from the outset in the first year, and to begin training the farm labour in the techniques and responsibilities associated with this important aspect of farm management.

In the scheme outlined briefly above, it was assumed that the management of the sheep flock would be that normally practised in the region: that is, mating the ewes at 19 months of age. If, on the other hand, the ewes can be brought rapidly to a mean weight of 35-40 kg, they can be mated earlier. If the lambs are weaned at 3 to 4 months of age and brought rapidly to the desired weight, breeding can take place in March for the main group and in May for the ewes of the year. This would mean two lambing periods (August and October) and the weaning of two crops of lambs in every year, giving an annual increase of an additional 49% in the growth of the breeding flock. Hoggets for sale would be available for sale in both January and March, times which bring good prices for such livestock.

4) Financing the development plan

A certain amount of medium and long-term credit is available in Chile for approved farm development plans in cases where the farmer can show that he has adequate funds to participate fully in the development. In the case outlined above, for a farmer of modest means a sum of at least US$ 25,000 must be available at the outset of the project. This might come from four possible sources: (1) long-term credit and loans from CORFO; (2) one-year loans for the purchase of livestock made available by the livestock marketing agencies at the high interest rate of 2% per month; (3) annual loans on the growing of wheat, made available by the Banco del Estado, which must be repaid on the harvesting of the crop, and (4) the private resources of the farmer. Table 2 shows the total amount essential under each main sub-head, the amount to be borrowed, and the rate at which the borrowed money can be paid off out of farm income. The return from farm operations during the first year is estimated to be US$ 10,000, out of which some US$ 4,000 would need to be allocated to the repayment of loans coming due at the end of the first year (table 3). In the second year, the return from farm income is likely to rise to about US$ 16,000, but approximately US$ 13,000 would have to be repaid in this year, leaving a smaller profit to the farmer. In the third year, a very much smaller sum would still be outstanding from the loaned money, and farming profits would be very much higher, so that a comfortable balance would be available to the owner for effecting further improvements in his farm and for the construction of some new farm buildings. The situation is even better in the fourth year, and by the fifth year the farm would be debt-free, and showing a very handsome profit on the year's working.

However, this rosy prospect depends on the farmer adhering very closely to all the major aspects of the development programme. Neglect of any of the major aspects will start a chain reaction, influencing the operation of other vital parts of the scheme, so that the farmer may find himself, at the end of the fifth year, in the unfortunate position of having to borrow more and more money to keep the farm going.

5) Technical assistance

During the early years of the development programme, most farmers will need supporting technical advice. In the Ministry of Agriculture there are two valuable Departments (Technical Assistance and Soil Conservation) which have regional personnel available for just this purpose, and, in the same Ministry, there are a number of trained veterinary and livestock health experts. In the long run, however, the farmer must learn to depend more and more on his own resources, - to recognise and remember his mistakes, and to train an adequate number of his farm labour force in the essential routine of farm management. In a large measure the success of a venture such as that outlined above will depend on proper timing: financial arrangements must be ready ahead of the date of starting operations; equipment, seed, fertilizers must be acquired in advance and stored properly; the proper time of season for starting each operation must be considered in advance and the seasonal time-table adhered to as far as local fluctuations in weather conditions will alow; requests for technical assistance must be forseen as far as possible in the case of farms remote from rural centres and emergency situations kept to a minimum; - all this makes it essential that the farmer live continuously on his land to maintaining a continuous watch on the progress of his livelihood. To a great degree, the current high rate of interest on money loaned for farm development is the result of losses due to money being loaned for agricultural schemes in which the farmer-borrower is not consistently 'on the job' but tries to manage his farm from a town headquarters, thereby failing in the first essential of good farming.

PART IV

NATURE, ORIGIN AND CLASSIFICATION OF CHILEAN ALLOPHANIC VOLCANIC ASH SOILS

a) Introduction

In this part of the report, it is proposed to take examples of the main kinds of allophanic volcanic ash soil, - mainly trumaos and ñadis, - and discuss at somewhat greater length their morphology (i.e. their appearance in profile), their chemical characteristics, their genesis, their nomenclature and their possible classification. The trumao group will be considered first, and the ñadi group will be considered later on. Within this grouping, representative soils from each of the six environmental (weathering) zones listed in Part I, section (c) will be described; as far as possible examples will be given of soils with different modes of formation (i.e. sub-aerial ash, volcanic loess, volcanic alluvium, etc.) and from strongly contrasting parent materials (e.g. pumiceous and fine andesitic ash). In the text, references to soil morphology will be kept as concise as possible, emphasising only the most significant characters of the profile which are necessary for recognition in the field. Additional data, of a more detailed type, will be found under the appropriate profile number in the Appendix.

b) Trumao soils of environmental zone 1

Allophanic volcanic ash soils are comparatively rare in this zone. They occur mainly as small patches on broad ridges of the Andean cordillera, on narrow, high terraces bordering some cordillera streams; a somewhat more extensive area occurs on the north bank of the Maule river where it first enters the plains of the central vale, and small areas occur along the coast near the boundary between Maule and Ñuble Provinces. The last two kinds of soil are clearly derived from volcanic loess, but it is also very likely that most of the cordillera trumao soils in this zone are also, in part, of loessic origin.

1. Environmental characteristics of the zone

Mean annual precipitation ranges from 800 mm to 1200 mm, of which more than 50% falls during the winter months. There are five 'dry' months (in which rainfall is less than 60 mm) in every year, and probably as many as seven months in each year when evaporation exceeds precipitation. Mean annual temperature lie between 13°C and 15.5°C, with mean summer temperatures in the range 24°C to 30°C; and mean winter temperatures in the range 9°C to 10.5°C. Almost no snow falls in winter but often very hard frosts.

Topographically, the soils are mainly developed on rather strongly rolling relief, with only relatively small areas of undulating or hilly relief carrying closely comparable soils. Most moderately steep and steep slopes do not have allophanic soils in this zone.

The natural plant cover was invariably forest, with a predominance of small-leaved evergreen, semi-xerophytic trees (such as boldo, litre, maitén, quillay, etc.); a second story (under-canopy) of more definitely xerophytic shrubs; and, in a few places, deciduous Nothofagus obliqua, var. 'maulino', - the "roble maulino" of common parlance.

The parent material of the soils is everywhere very fine to fine andesitic sand, with a high proportion of quartz. Only in the case of related soils developed around la Laguna del Maule, at 2100 m altitude, is the coarse sand fraction considerable.

The associated non-trumao soils of this zone are mainly Non-Calcic Brown Soils and Grumosols.

2. General soil morphology

Topsoils:
- generally 15 to 30 cm in depth, occasionally 50 cm;
- textural range, loamy sand to fine sandy loam;
- colour, very dark gray brown (10YR 3/2) to dark brown (7.5YR 3/2) when moist;
- friable to very friable; with a weakly developed;
- fine subangular blocky structure breaking to very fine granules and crumbs;
- non-sticky and non-plastic when moist; boundary distinct;

Subsoils:
- about 60 cm to over 100 cm in depth, showing little sign of depositional stratification;
- textural range narrow, loams to very light clayloams;
- colour brown (7.5YR 4/4) or reddish brown (5YR 4/3), grading to reddish brown (5YR 4/4 or 3/4), rarely red (2.5YR 4/8);
- friable; weakly developed medium or coarse blocky structure breaking to irregular granules; generally
- non-sticky and non-plastic when moist; boundary diffuse.

3. General chemical characteristics (see tables 1a and 1b)

Topsoils: natural topsoils have -
- near neutral reaction (pH 6.1 to 7.0)
- organic matter content, high (13% and upwards)

- cation exchange capacity, very high (48 to 67 m.e.%)
- exchangeable calcium, very high (16 to 28 m.e.%)
- base saturation, medium to high (41 to 58%)

<u>other topsoils under vegetation other than natural have</u> -
- slightly acid (pH 5.6 to 6.1) reaction
- organic matter content, medium (8.5 to 11.0%)
- cation exchange capacity, very high (51 to 69 m.e.%)
- exchangeable calcium, low to medium (3 to 7 m.e.%)
- base saturation, very low to low (7 to 18%)

Subsoils: <u>natural subsoils have</u> -
- near neutral reaction (pH 6.5 to 7.1)
- organic matter content, very low to low (0.5 to 4.2%)
- cation exchange capacity, high to very high (32 to 61 m.e.%)
- exchangeable calcium, medium (4 to 7%)
- base saturation, low (9 to 22%)

<u>other subsoils have</u> -
- near neutral to slightly acid reaction (pH 5.7 to 6.7)
- organic matter content, medium to low (3.6 to 8.4%)
- cation exchange capacity, high to very high (39 to 67 m.e.%)
- exchangeable calcium, very low to low (1.4 to 5.4 m.e.%)
- base saturation, very low to low (5 to 21%)

Observations - chemical analyses are available for eight soil profiles, of which one (that from near la Laguna del Maule) is only a distant relative of the soils in this group and is markedly more pumiceous. No analyses are yet available for the related soils found in Aisén Province at the margin of the Patagonian pampa (Ñirreguao soils). Three of the analyses available are from soils under natural forest, and five are under volunteer pastures that grew after the forest had been cleared.

Under natural conditions the soils are moderately fertile, although most of this fertility apparently resides in the organic fraction. Possibly much of the fertility in the subsoil also is due to the relative deep organic matter penetration.

When the natural forest is removed, there is some diminution of the organic matter content (but little corresponding change in topsoil colour), and a very marked reduction in exchangeable cations, especially calcium which was one of the elements accumulating strongly under the original vegetation.

The high cation exchange capacity of these soils is of course typical of all allophanic soils, and this is responsible for the very low figures for percentage base saturation, (table 4a).

Total fusion analyses are available for some of these soils. These show (table 4b) that the total mineral reserve is not very high: total calcium (as CaO) ranges from 0.2 to 0.6%; total magnesium from 0.1 to 1.3%; total potassium from 0.5 to 1.1%, and total sodium shows unexpectedly high values, from 1.2 to 1.8%. The silica/alumina ratios lie between 0.6 and 0.8; while the silica/sesquioxide ratios are between 0.5 and 0.7. Total phosphate lies between 0.5 and about 2.0%.

Although these soils are but slightly weathered, the weathering environment is weak and is unable to replace the nutrient elements lost as a result of normal leaching, once the natural forest cover has been destroyed.

The related soil from the vicinity of la Laguna del Maule has a much lower cation exchange capacity (which is only 18 m.e.% in the subsoil, and even lower, 9 m.e.%, in the topsoil owing to some deposition of recent pumiceous ash); has a relatively high calcium content (1.5% total, and 11 m.e.% exchangeable, in the subsoil); and has a base saturation of between 66% and 78%. This soil should thus be regarded as an intergrade to the Recent Volcanic soils.

4. <u>Characteristics of typical soils</u>

In this zone we few have examples of soils derived from volcanic alluvium,but many from volcanic loess, and from soils that are derived in part from sub-aerial material, and in part from loess. The only soils derived mainly from sub-aerial materials are those of Aisén Province, and the altiplano region of la Laguna del Maule. Five of these soils are described below:-

i) <u>Hornillos fine sandy loam</u> (Appendix, profile No.11)

This soil is derived in part from volcanic loess and in part from sub-aerial ash, and is developed on the broad rolling ridges and saddles of the Andean cordillera at altitudes of from about 500 m to 900 m, under light forest dominated by Nothofagus obliqua (var. 'maulino'), with radal, canelo, and other evergreen species.

The profile shows:

25 cm dark brown fine sandy loam, very friable and granular (field pH, 5.9; lab., pH 5.6);
20 cm dark reddish brown sandy loam, somewhat firm and coarse nutty structure (field pH, 5.6; lab., 5.8);
100 cm brown very light clay loam, firm and with a coarse angular blocky structure (field pH, 5.9; lab., 6.0),
On.. strong brown silty clay loam, firm and with an irregular subangular blocky structure (field pH, 6.0; lab., pH 6.3); contains fragments of weathering andesitic rock, giving slight red mottle.

This soil builds up a large amount of organic matter in the topsoil under forest, particularly rich in exchangeable calcium, magnesium and potash. When the forest is cleared, after a very few years, there is a sharp drop in these nutrient elements, and the organic matter slowly moves down through the subsoil and diminishes in quantity. Although the soils are fairly rich in reserve of phosphate, in some cases, yet the rate of release is likely to be slow and the released phosphate is certain to be attracted to the large number of anion-exchange surfaces and thus will not be readily available to plants.

For establishment of high producing pastures on these soils, regular dressings of phosphatic fertilizers are essential, and it is entirely possible that, once the phosphate requirement of the soil has been built up that pastures and crops will then show a response to liming.

ii) Maiten very fine sandy to silt loam (Appendix, profile No.12)

This soil is derived mainly from volcanic loess, and some of the underlying beds may perhaps be formed from ancient volcanic alluvium. It is developed mainly on gently undulating to rolling landscapes along the front of the cordillera foothills, near the point where the Maule river enters the plains of the central vale, and is most extensively developed on the north bank of the river. It occurs at altitudes ranging from 400 m to about 550 m, and originally supported an evergreen forest (litre, boldo, maitén, arrayán, etc.) with occasional deciduous "roble maulino".

The profile shows:

30 cm very dark brown very fine sandy to silt loam, friable, and with a very weak fine blocky structure that breaks readily to crumbs and granules. (field pH, 5.7; lab., pH, 5.8);

40 cm dark brown silt loam, very slightly firm and with a distinct coarse blocky structure, breaking under slight pressure to coarse granules. (field pH, 5.9; lab., pH 6.2);

80 cm between dark yellowish and dark reddish brown heavy very fine sandy loam with occasional small stones, somewhat firm and with no visible structure in place but breaks to coarse and fine blocks and granules. (field pH, 6.0; lab., 6.2),

On.. dark yellowish brown fine sandy clay loam with occasional stones indicating stream bedding, usually rather compact.

This soil is a very valuable farming asset, since it has a slightly lower cation exchange capacity, and a much higher subsoil base status than the majority of trumao soils in the zone. It has a relatively high phosphate reserve, and the 'phosphate fixing power' of these soils is probably rather less than for the majority of trumaos. It is moreover, moderately well supplied with exchangeable calcium, magnesium and potash, even for some years after the original forest has been removed.

Intensive pastoral use or cropping will require the application of phosphatic fertilizers and nitrogen, but this problem may prove to be less acute in this soil than the preceding Hornillos soils.

iii) Tregualemu very fine sandy loam (Appendix, profile No.13)

This soil is probably derived mainly from volcanic loess since it shows very little stratification or variation in texture. It occurs in isolated patches just below the crest of the coastal ranges, on the seaward side, and is thus at a considerable distance from the Andean cordillera. In part it is composed of materials of local origin (the dust eroded from adjacent tuffaceous shales), but in some localities it is perhaps in part composed of fine volcanic dust carried up from the coastal lowlands. Its distribution coincides with the parts of the coastline where there has been coastal uplift of the shore through seismic action. It is generally developed on landscapes of rolling relief, at elevations of between 150 to 350 m, under a natural forest of evergreen species in which boldo, litre and arrayán are prominent.

The profile shows:

15 cm very dark gray brown very fine sandy loam, friable and breaking to very fine subangular blocks and granules. (pH in field, 6.3; in lab., 7.0);

65 cm brown to dark reddish brown loam to silty clayloam, usually very friable (somewhat powdery when dry), with a very weak medium blocky structure. (field pH, 6.4; lab., 7.1);

20 cm dark reddish brown to brown silty clayloam, somewhat firm, and without clear structure in place but breaking to weak coarse irregular blocks when disturbed. (field pH, 6.0; lab., 6.5),

On.. compact mottled clayey beds with an ancient line of stones forming an erosion pavement along the line of contact with the horizon above.

Although of small total extent, Tregualemu soils have a good farming potential. Like the Maiten soil, they have a lower cation exchange capacity than most trumao soils, and hence one may expect that fertilizer applications will give better results than on the normal trumao soils - especially phosphatic fertilizers. Also the base status of the subsoil holds up well under farming. The soils are moderately well supplied with exchangeable calcium, but less well supplied with exchangeable magnesium and potash than Maiten soils.

Intensive farming on these soils will nevertheless require regular application of phosphates, and also nitrogen.

iv) Ñirreguao fine sand (Appendix, profile No. 14)

This is a recently discovered soil of the Patagonian pampa margin in Aisen Province, and relatively little information is available concerning its chemical properties at the time of writing. These are 'trumao-like' rather than trumao soils, but with increasing age they are likely to become closer to the real allophanic soils, and mainly for this reason they are permitted within the scope of the present enquiry.

These soils are derived mainly from subaerial volcanic ash, of general andesitic composition, and are developed at elevations of about 700 m, in the cool to cold sub-humid environment of the Patagonian pampa margin. They are developed under Dwarf Nothofagus (ñirre) forest, on landforms of gently undulating, rolling and nearly flat relief.

The profile shows:

12 cm dark reddish brown to dark brown very friable and powdery loamy sand;
10 cm dark brown to dark yellowish brown very friable weakly structured sand;
28 cm yellowish brown very friable coarse sand,
On.. pale yellowish brown very coarse sand with fine pumice gravel.

Farming on these soils is restricted mainly to grazing on volunteer grasses (mainly Festuca tussocks that appear when the forest is cleared).

It is expected that these soils will have a cation exchange capacity of between 25 and 30 m.e.%; medium base saturation (35%) and a moderate calcium status. The soils would be likely to respond well to nitrogen and to phosphate but heavy applications of the latter fertilizer would probably not be economic unless the whole farm management planning was on an intense scale with selection of suitable high-producing grasses and clovers suited to the environment and careful stock management on properly subdivided farm properties.

v) Laguna del Maule loamy sand (Appendix, profile No.15)

This soil is another that is 'trumao-like' in some aspects and not a thoroughbred trumao soil. It is derived mainly from pumiceous volcanic ash of subaerial origin, but there has also been a considerable degree of secondary movement by wind: hence it is best regarded as part subaerial and part loessic in origin. These soils are found only high in the Andean cordillera, at altitudes between 1800 and 2200 m, on gently to strongly undulating plateau landforms, under a natural vegetation of tussock grassland.

The profile shows:

40 cm very dark gray brown loamy sand, very friable and virtually structureless. (field pH, 5.8; lab., 5.1);

45 cm reddish brown to reddish yellow heavy sandy loam, which is slightly firm, slightly sticky when moist, and has a weakly developed irregular blocky structure that breaks to granules and crumbs under pressure. (field pH, 6.2; lab., 6.2),

On.. weathering andesitic rock.

This soil is very fertile, with a high base saturation and a very good supply of calcium and magnesium, especially in the topsoil. The cation exchange capacity is quite low, and probably this soil would not 'fix' added phosphate in very large amounts. The amount of exchangeable potash is rather low, and the amount of organic matter is definitely low.

Farming operations are restricted to occasional grazing during the summer months, and the long cold winter probably would limit the use of this soil for any of the more intensive methods of farming.

5. Soil genesis

All the soils included in environmental zone 1 are subjected to rather weak weathering processes, and also relatively slight-to-moderate leaching processes. Under natural conditions, the vegetation plays an important part in minimising the loss of fertility due to leaching: nutrients are captured by the roots and passed in circulation through the body of the vegetation, to be returned to the soil surface, where they accumulate along with the organic residues of the vegetation. As is well exemplified by the analyses of Tregualemu and Hornillos soils under forest, leaching still operates but its impoverishing effect is mainly seen in the low base status figures of the subsoils. When the natural vegetation is removed, the effect of leaching can be seen in both topsoil and subsoil. Under these modified conditions, some of the organic matter is lost by direct oxidation, but a relatively large quantity moves down into the subsoil, where it is augmented by organic residues derived from the grass roots. Despite these organic matter changes, the topsoils still remain conspicuously darker than the subsoils, even after many years of farming: this is a definite characteristic of all allophanic soils, and probably is due to the formation of unusual and, so far, little known colloidal complexes between the humic colloids and the allophane mineral colloid. All the soils have a relatively high total alumina content relative to silica, and a low iron content.

Provisionally, until further mineralogical studies are made on these soils, it is proposed to regard them as Minimal Allophanic soils, developed in a zone of weak weathering and slight-to-moderate leaching, with no more than moderate melanisation.

6. Soil classification

In Chile, these soils are often barely admitted into the group called 'Trumao': it is only their similar physical characteristics, and their behaviour under farming that encourages some soil scientists to regard them as, at least, transitional to the Trumao group.

In the 7th Approximation of the North American school (1960) of classification these soils belong to the order of Inceptisols, suborder Andepts. Since there is no distinct cambic horizon developed, they are probably Entic Umbramdepts.

In the older classification of New Zealand (Taylor et. al. 1948) (Taylor & Cox, 1956), they are mainly weakly weathered Yellow Brown Loams and Yellow Brown Pumice Loams; in the latest New Zealand classification (Pohlen, 1962), they would probably be regarded as sub-alvic and alvic soils. They might be defined in full as "weakly to moderately enleached, weakly accumulating, sub-alvic and alvic soils from weakly argillised andesitic and rhyolitic ash and derived materials".

They are not Humic Allophane soils, in the sense used by Kanno (ibid, 1962), but they are 'allophanic' in the sense that colloidal amorphous allophane is their most significant and dominating characteristic: the characteristic from which almost all the chemical, physical and farming attributes spring.

c) Trumao soils of environmental zone 2

Allophanic volcanic ash soils are abundantly developed in this zone, but only over the Andean cordillera and the foothills; related soils derived from volcanic alluvium extend for a short distance on to the plains of the central vale but at a distance of about 20 km from the foot of the cordilleran foothills. No allophanic volcanic ash soils are seen on the lowlands or on the coastal hills, and none are found along the coast from the mouth of the Ñuble river southwards to the limits of Cautin Province.

Apart from the allophanic soils derived from volcanic alluvium, which have a flattish to very slightly undulating relief, and take the form of old alluvial fans tapering towards the Andes, the allophanic volcanic ash soils of this zone are mainly developed on undulating, rolling or very strongly rolling 'ceja de montaña' downland, and on the moderately steep to steep hills of the actual Andean cordillera. These soils thicken in depth towards the centre of the cordillera, despite the gradual steepening of the slopes. Even in the truly mountainous parts, the mantle of volcanic ash is almost complete, - being missing chiefly where erosion has followed destruction of the natural forest both by fire and by misplaced agricultural endeavours.

Considering the diversity of volcanoes in the zone (there are six major ones), the ash beds show a remarkable uniformity. The dominant soil forming material is an andesitic type of ash; sometimes intermediate to basic in composition, and elsewhere rather more acidic. The intercalated shower horizons are nearly always pumiceous and often clearly rhyolitic, and sometimes appear to have been emplaced as a mud-plaster. Pumiceous horizons are seldom at or near the surface of the ash mantle in this zone, and no soils derived entirely from pumiceous materials have been discovered; although such materials do occur amongst the deeper subsoil strata in a great many soils. Volcanic glass, magnetite, and various opaque minerals are a common constituent of all soil parent materials giving rise to allophanic soils in the zone (see table 5a).

1. Environmental characteristics of the zone

Mean annual precipitation ranges from about 1100 mm to over 2500 mm. The maximum occurs not along the Andean divide, but well to the west of the Argentian border, and approximately over the region in which the volcanoes are situated. Rainfall in the region of the Andean divide is probably less than 2000 mm. Only about 8% of the total rainfall falls during the warmer summer months, and as much as 45% falls during the cooler winter months. Along the western skirt of the cordillera at least three months in every year have less than 60 mm rainfall, and even over the cordillera ranges there is usually six weeks to two months in which evaporation exceeds precipitation. There is thus a very distinct, although relatively short, dry season. Over the foothills and adjacent lowlands, the dry season is more marked and somewhat longer: perhaps the soil environment may be characterised as one in which there is a moisture deficit for a period of up to eight weeks in every year. The ranges are regularly covered lightly with snow every winter, but this rarely extends to the lowlands although even here very cold nights are the rule in winter, and as much as 4° of frost have been recorded in December.

The mean annual temperature lies in the range of 15°C to 14.5°C, with mean summer (December) temperatures ranging from 28°C to 22°C, and mean winter (July) temperatures ranging from 9.5°C to 8.5°C. The climatic regime of the zone approximates to Thornthwaite's* category 'humid, mesothermal, summer rainfall deficiency: B B's '. Comparable, but by no means identical climatic regimes occur along the Tagus valley, north-east of Lisbon in Portugal, and in the south-west corner of Australia, near Albany (R.G. Simmers, N.Z. Meteorological Service, pers. comm., 1960).

Topographically, the soils are developed on landscapes of all types of relief, but the main farming soils are on undulating to rolling land.

The natural plant cover was park-like woodland dominated Nothogagus obliqua ('roble') on the outer foothills, with a more complete forest cover on the inner foothills and on the Andean ranges. The proportion of roble diminishes steadily with altitude, and its place is taken by other species

* See Thornthwaite, 1948.

of Nothofagus, notably coigüe (N. dombeyi) and ñirre (N. antarctica): the latter is usually found only at high altitudes. Roble is one of the deciduous species of Nothofagus, and its dissappearance from the canopy coincides with the beginning of the evergreen forest, in which laurel (Laurelia sempervirens), canelo (Drimys winteri) and olivillo (Aextoxicon punctatum) are important trees, in addition to the evergreen species of Nothofagus. Podocarpus nubigensis (mañio) is common in the higher valleys, and Pilgerodendron sp. ('cipres') appears on the scoriaceous river terraces near the volcanoes. In the more immediate vicinity of the volcanoes, the forest has been destroyed by noxious gases, and coarse tussock grass communities appear.

The associate non-trumao soils in this zone are mainly Non-Calcic Brown soils intergrading to Brown Lateritic soils, and to Brown Forest soils; Brown Forest soils; and Red-Brown Latosolic soils (Roberts, et. al. 1958).

2. <u>General soil morphology</u>

Topsoils:
- generally between 20 and 40 cm in depth, except in soils derived from volcanic alluvium where total topsoil depth may reach 70 cm;
- textural range generally finer than for soils of Zone 1, the majority of soils being very fine sandy loams, although the range in field texture lies between sandy loam and silt loam (mechanical analyses on properly dispersed materials indicate that the textures are clay);
- colours are predominantly dark brown or dark grayish brown when dry; darkening to very dark brown or very dark gray brown when wet (10YR 3/3, 7.5YR 3/2, 10YR 5/2 dry: 10YR 3/2, 10YR 2/2, 7.5YR 3/2-2/2, moist);
- usually very friable under natural conditions but may become slightly firm under pasture, - never compact;
- weakly developed fine subangular blocky structures are very common in the topsoil, and these break easily to very fine granules and crumbs; very light volume weight, and somewhat difficult to wet, in respect of individual granules; rather 'fluffy' when dry;
- usually non-sticky but very slightly plastic when moist;
- boundary usually quite distinct, even sharply defined under pastures, but slightly blurred and irregular under natural forest.

Subsoils:
- mainly dark yellowish brown, grading to yellow brown in the dry condition (10YR 4/4 grading to 10YR 5/4 or 5/6); colour changes very markedly when in wet condition for the dark yellow brown upper subsoil material changes to dark brown (7.5YR 3/2) or even dark reddish brown (5YR 3/3) while the lower subsoil changes to dark reddish brown (5YR 3/4) or reddish brown (5YR 4/4), except for some of the older pumiceous

shower layers which change to strong brown (7.5YR 5/6 or 5/8);
- subsoils are usually stratified, and may have prominent pumiceous layers, and subsoils range in total depth from about 1 metre to as much as 4 metres;
- the textural range is wide, from heavy silt loam to light clay loam, with pumiceous layers ranging from sandy loam to gravelly clay loam;
- the upper part of the subsoil is typically very friable, very soft and powdery when dry, and soon collapsed in a freshly excavated roadside cutting; by contrast the lower subsoil horizons are much less friable, often quite firm, and they tend to harden slightly on drying so that the older roadside cutting typically have a bulging lower profile and a hollowed out upper part, above which the root-bound, less friable topsoil hangs like a mantle (see sketch opposite);
- structural aggregation is poor in the upper part of the topsoil, being restricted to very fine granules and crumbs; but with increasing depth there is a quite sharply defined lower subsoil boundary below which the aggregates are large, quite well formed, and with increasing pressure break into very fine blocks and fine granules; some of the medium and fine subangular blocky aggregates of the lower subsoil show signs of weak clay flows, but this feature is not well developed in the soils of this zone; a rather special feature of these soils is the presence of numerous firm, roundish, nodular aggregates amongst the friable material of the upper subsoil, - possibly these are of insect or worm origin, but since they persist in agricultural soils after many years of farming under an entirely different biota, they may be aggregations of amorphous allophane formed by the seasonal drying out of the soil; these nodules have none of the obvious characteristics of gibbsite; root penetration is excellent, and often reaches to over 1 metre;
- the subsoil materials are usually non-sticky when moist, but may be slightly or moderately plastic, - this feature appearing only when the moist soil is worked in the fingers for a considerable time;
- the typical 'slipperyness' or 'greasyness' associated with soils rich in allophane clay, is not immediately apparent in some of these allophanic soils, unless the soil has been in a naturally moist condition for some time; under summer dry conditions, this phenomenon cannot be noted until the soil has been moistened and worked in the hand for a considerable time;
- the lower subsoil boundary is usually sharply defined.

3. General chemical characteristics (see tables 5b, 5c and 5d)

Topsoils: analysis of the mineral composition of the topsoils shows the presence of dominant allophane, with some mineral-organic complexes, iron gels, quartz, cristobalite, lepidocrite and geothite; many of these may be recent contaminants from road dust (which is very prevalent in areas of trumao soils) since they are found only in the top 5 cm; goethite and cristobalite are the only minerals beside the abundant allophane to be found in the lower part of the topsoil, although gibbsite appears quite near the soil surface; the presence of gibbsite and allophane together in the same part of the profile seems to be a rather common characteristic of Chilean trumao soils in this zone, and is one of the distinctions that separatesthem from the allophanic volcanic ash soils of New Zealand;

topsoils under their natural plant cover -

- are slightly acid to weakly alkaline (pH 5.7 to 6.5);
- have a very high organic matter content (over 30%);
- have a medium to high cation exchange capacity (20-40 m.e.%);
- have high to very high exchangeable calcium (10-30 m.e.%),
- have a high base saturation (65-80%)

other topsoils, under vegetation other than the natural one -

- have a pH near neutral (pH 6.8) to alkaline (pH 7.5);
- have decreasing organic matter with depth, but often still quite high levels (13-15%) near the surface;
- have high cation exchange capacities (30-37 m.e.%);
- have rather high exchangeable calcium (about 9 m.e.%),
- have low to medium base saturation (30 to 40%).

Subsoils: show a rather restricted range of clay minerals, with allophane still dominant, but with gibbsite increasing in quantity with increasing depth; accessory minerals are cristobalite, goethite and occasionally, boehmite and iron gels;

natural subsoils have the following characteristics -

- pH ranging from slightly acid to alkaline (5.1 - 8.3);
- organic matter decreasing very sharply with depth, but even at over 1 metre there may still be over 4% of organic matter present (range 3.3 to 16.3);
- cation exchange capacities between 33 and over 90 m.e.% i.e. in the range medium to very high;
- exchangeable calcium ranging from very low (0.9 m.e.) to slightly better than medium (4.6 m.e.),
- base saturation very low (range 5% to 11%) .

subsoils of agricultural soils show -

- pH commonly weakly alkaline (7.0 to 7.9);
- organic matter content decreasing with depth, from high

(10%) to low (2.8%), the latter at over 1 metre;
- cation exchange capacities medium to high (24-41 m.e.%);
- exchangeable calcium generally high (8 to 10 m.e.),
- base saturation medium (30 to 50%).

Observations - chemical analyses of base status are available for four soil profiles only, and all of these are from the foothill region where the parent material is dominantly volcanic loess mixed with subaerial shower material. No analyses are yet available for the wholly subaerial trumaos, nor for any of the related soils from the southern province of Aisén, nor for the trumao-like soils derived from volcanic alluvium in this zone. Of the analyses available, two are from areas under natural roble forest, and two are pastured areas that are carrying rather poor, rough pasture at the present time but almost certainly have been periodically under cultivation and cropping (mainly wheat).

Under natural conditions, the soils show a good build up of fertility in the topsoil, almost certainly residing in the organic fraction. This topsoil fertility decreases rapidly when the soils are brought under farming regimes.

In contrast to the trumao soils of zone 1, there is no marked loss of exchangeable cations from the soils when farming commences. Both the available analyses show that the levels of subsoil exchangeable calcium and magnesium are well maintained, despite the fact that the rainfall is considerably greater in zone 2. This may be the result of fertilizers added during farm operations, but it may, more likely, be due to the stronger weathering processes having a deeper effect once the forest is removed.

Scanty information is available concerning the total nutrient reserves in these soils. The information in table 2d does little more than confirm that the total alumina is higher than the total silica, and that the total iron is relatively low.

On the evidence available, it is provisionally estimated that the soils are in a slightly more advanced weathering environment than the soils of the preceding zone, and that these processes are able to replace part of the nutrient lost by normal leaching, perhaps, more especially under the rather higher soil temperatures that exist when the forest is removed. Only casual, "spot" records are available to substantiate this latter point, but actual measurements on several occasions showed that differences of between 10 and 20°C frequently existed between forested and non-forested soils down to a depth of 50 cm. On one occasion, during a hot dry summer the soil at a depth of 35 cm was slightly moist and was actually 25°C warmer than the soil under forest at the same depth. Provisionally these soils are considered as sub-moderately weathered trumao soils.

4. Characteristics of typical soils

In this zone we have many examples of trumao soils derived from volcanic loess and from subaerial ash and shower deposits. There are also a few soils formed mainly from volcanic alluvium. One of the latter soils will be discussed, and three of the soils formed volcanic loess mixed with ash shower materials. A fifth soil, developed from mainly subaerial materials in the far south near the margin of the Patagonian pampa, will be described for comparative purposes.

i) Santa Barbara very fine sandy loam, Chillán facies (Appendix, profile 16)

This soil is derived mainly from subaerial volcanic material with some admixture of volcanic loess, and is developed on strongly rolling landscapes near the Andean foothills, about 30 km southeast of Chillán. Here the mean annual precipitation is about 1350 mm, and the mean annual temperature is about 14.7°C. The region experiences at least two dry months in each year. The soil occurs at elevations of from 500 to over 1000 m, and the natural plant cover was mainly roble (Nothofagus obliqua) forest with an abundance of lauriform-leved evergreen trees.

The profile shows:-

20 cm dark brown to brown, very fine sandy loam, friable and very finely granular, with many roots. (field pH, 6.0; lab., pH, 6.5);
30 cm very dark yellowish brown, very fine sandy loam or silt loam, very friable and porous, (field pH, 6.3; lab., 7.3);
40 cm dark yellowish brown grading to yellowish brown, slightly firm heavy very fine sandy loam or loam, with a weakly developed blocky structure. (field pH, 6.4; lab., 8.0),
50 cm yellowish brown, rather firm, silty clay loam, with a distinct subangular blocky structure and moderate plasticity when moist. (field pH, 6.6; lab., pH, 8.3).

This soil is developed in slightly stratified materials, but to a depth of about 140 cm the stratification is not very obvious unless samples are examined under the microscope. Below 140 cm there are very conspicuous pale yellowish to strong brown layers of weathered pumiceous ash (slightly gravelly compact sandy clay loam; pale brown strongly structured silty clay, etc.), interlayered with yellowish brown silty clay loam comparable in many ways with the last horizon described in the profile above.

The farmed soils are extremely deficient in available phosphate and have a very high 'phosphate fixation' index (up to 90% of all phosphate is fixed in these soils: O. Schenkel, 1962, pers. comm.). Crops respond to nitrogen and to phosphate, and in the absence of phosphate many crops give no yield at all. Small phosphatic dressings applied in close proximity to the seed appear to give more economic results than very large dressings applied generally to the soil surface.

ii) Santa Barbara very fine sandy loam, Santa Barbara facies (Appendix, profile No. 17)

This soil is derived mainly from volcanic loess with some slight admixture of shower material, and is developed on rolling downlands between the cordillera foothills and the plains in the province of Bío-Bío. Mean annual precipitation is about 1400 mm, with up to two dry months in the year. The mean annual temperature is about 13.5°C, with mean winter temperatures about 8.5°C and mean summer temperatures about 19.3°C. This soil occurs over an altitudinal range of about 350 to over 700 m, and the original plant cover was roble forest, in part, open park-land.

The soil profile shows:-

20 cm dark brown very fine sandy loam with slightly more clay than the Chillán trumao soil, finely blocky and granular. (field pH, 6.0; lab., pH, 6.8);

25 cm brown silt loam, rather 'fluffy' when dry and with a very fine granular structure. (field pH, 6.1; lab, pH, 7.0);

80 cm yellowish brown heavy silt loam which dries with an incipient prismatic structure. (field pH, 5.9; lab., 7.5);

95 cm strong brown silty clay loam with a strong blocky structure when moist but forms columns of prisma when dry. (field pH, 5.4; lab., 7.4),

On.. compact yellowish brown stratified volcanic ash.

This soil appears to lie within the range of the Santa Barbara soil association, but it differs significantly from the Chillán trumao soils in its slightly heavier field textures, the tendency for the subsoil to shrink into roughly columnar patterns in dry road banks, and perhaps in rather stronger yellow colours. Both soils have the very friable and 'fluffy' upper subsoil horizon with hardened rounded 'soil nodules', and the incipient presence of weak clay flows in the lower subsoil.

Agriculturally, they are closely similar soils. The Bío-Bío trumao soils of this sort, are farmed almost identically with the Chillán trumao soils, and have the same problems of very high phosphate fixation. Both give a good nitrogen response.

iii) Santa Barbara very fine sandy loam, Mulchén facies (Appendix, profile No.18)

Again this is a very similar soil to that described as typical of the Chillán trumaos derived from volcanic loess and subaerial ash. This soil is developed some 200 km further south than the latter soil but on part of the same longitudinal strip of ash lying between the cordillera foothills and the plains. The climate of the Mulchén region is slightly wetter, with about 1500 mm annual rainfall over the locality where these soils are best developed; and a mean annual temperature of about 8.2°C. There are usually about 2 dry months in any year. The soils are developed on undulating, rolling and even flattish landscapes, under a natural plant cover of roble forest which is less open than was the case with the Santa Barbara soils of central Bío-Bío Province.

The soil profile shows:-

25 cm dark, rather reddish, brown very fine sandy loam or loam, finely granular in structure and friable. (field pH 5.4);
10 cm brown, very loose and friable loam with many rounded nodules of aggregated soil that are markedly more firm than the general soil mass. (field pH, 5.6);
30 cm brown grading to yellowish brown silty clay loam, which forms wide shrinkage cracks when dry and the shrunken soil columns have a roughly prismatic structure. (field pH, 5.8);
60 cm dark yellowish brown well-structured silty clay loam, which likewise shrinks strongly on drying. (field pH, 6.0),
On.. stratified yellowish brown ash beds and shower layers.

This soil represents the more weathered member of the Santa Barbara association, although it is still no more than sub-moderately weathered on the broad weathering scale. This soil has a much higher cation exchange capacity than most of the Santa Barbara soils, and also has an extremely high phosphate 'fixing' capacity (up to 95%). Possibly for this reason, the soil appears to be slowly going out of cultivation in recent years, or, at least, farmers are employing a longer rotation under pasture than formerly. The farmed soils are rather low in lime and potash, but the chief limiting factor is certainly the phosphate problem.

iv) Arrayán silt loam (Appendix, profile No. 19)

This is one of the many kinds of trumao soils derived from volcanic alluvium. Characteristically they all have rather dark, deep topsoil horizons, and the dark colours fade gradually to dark yellowish brown in the subsoil. Textures are mainly silt loams in the topsoil and fine sandy clay loams or slightly sandy loams in the subsoil.

Arrayán silt loam is developed on flattish to very gently undulating landscapes from old volcanic alluvial fan materials, dominantly andesitic but containing more admixture of fine quartz than most other trumao soils in the zone. This soil is developed under the full climatic range of the zone, and the original plant cover was probably roble parkland forest.

A typical profile shows:-

50 cm very dark gray silt loam, rather firm in its farmed state, and with a good granular structure providing the farmer with an excellent tilth after ploughing;
90 cm yellowish brown or brown somewhat sandy loam to heavy fine sandy loam (this may vary a good deal within a very restricted area), also with a well developed structure,

On.. brownish yellow sandy clay loam, which is usually resting on gravel at between 150 and 200 cm.

These soils have a rather high cation exchange capacity and show quite strong phosphate fixation even after many decades of farming. Nevertheless, they are extremely valuable agricultural soils, maintaining their dark colour and humus content well under all farming conditions.

v) Baguales fine sandy loam (Appendix, profile No.20)

Baguales soils are developed under much cooler conditions but under about the same annual rainfall, with somewhat similar pattern of rainfall distribution, as the other trumao soils in this group. They are above all the trumao soils of the eastern side of the Andean cordillera, in about latitude 35°S, in Aisén Province. Under natural conditions they support lenga (Nothofagus pumilio) deciduous forest and sometimes also ñirre (N. antarctica) forest and scrub-forest.

The climate of these soils is dominated by the frequent very strong, cold southwest winds which drop much of their moisture in the passage of the cordillera, and bring rain on about 150 to 180 days of the year, with a total precipitation of 1000 to 1200 mm per annum. Spring and summer months are noticeably drier than the rest of the year but it is doubtful whether there is any truly dry month. Another difference is that there is more snow in winter, and considerably colder winter temperatures (mean July temperature, 6°C). The mean summer temperatures (January, mean 14°C) are not so very different from the main region of the Santa Barbara and closely related soils.

A typical profile shows:-

20 cm dark brown fine sandy loam, friable and with a fair granular structure;
20 cm brown sandy loam, slightly firm and with a distinct blocky structure;
40 cm dark yellowish brown heavy sandy loam, firm, and with a less pronounced blocky to granular structure,
On.. gravelly sands and sandy clays, mainly of glacial origin.

No chemical data is yet available concerning these soils. It is expected that they will prove to be rather less weathered and somewhat more leached than the Santa Barbara trumao soils, yet still fall within the sub-moderately weathered category, and will have allophane as the dominant clay mineral. From the information gathered from farmers on these soils, - and farming experience is rather less extensive than in the case of the Santa Barbara soils since farming endeavours commenced much more recently in Aisén Province, - it would appear that phosphate fixation is a major problem on these soils, and that the main fertilizer requirements are nitrogen, and phosphate. It is also anticipated that much of the natural fertility of these soils resides in the organic topsoil horizon build up under the forest, that the subsoils are relatively poorly supplied with readily available plan nutrients, and that, as a consequence, the need for a balanced fertilizer programme on farms will become more apparent as the years pass.

5. Soil genesis

Soil processes that were evident in the trumao soils of zone 1 are operating with slightly greater force in the trumao soils of zone 2. The modal soil for the trumaos of this zone has long been regarded as the Santa Barbara soil in the Santa Barbara district (see Rodriguez, 1949), and a simple microscopic examination of the topsoil and subsoil materials of this soil shows that the horneblende and hypersthene minerals are much more strongly attacked than in the Hornillos and Tregualemu soils. Mechanical analyses are a less useful guide to soil weathering in trumao soils, mainly because of the great difficulty in obtaining full dispersion of the material. Usually the 'clay fraction' is far from complete, and much of the clay settles out with the 'silt fraction' due to the ease with which allophane aggregates under natural conditions in Chile, subsequently the aggregated particles behave like silt because they do not readily return to their amorphous state. Nevertheless, the topsoils of the trumaos in zone 2 do contain up to 50% more clay in their composition than those of zone 1.

There appears to be little difference in the intensity of leaching between the two zones; the difference is mainly one of intensity of weathering and the formation of aggregates of allophane under the seasonally dry conditions. The presence of gibbsite in some quantity (see table 5b) in the same profiles along with the allophane is a most interesting feature, and suggests that the soil environment is sufficiently rich in alumina for part of the amorphous allophane to crystalise directly to gibbsite. Typical waxy aggregates of gibbsite have never been reported from these soils, but it may be present as very fine material, dispersed through the soil, - or may even be, in part, responsible for the formation of the rounded earthy nodules that occur so commonly in the subsoils.

It has been long known that many trumao soils have comparatively large amounts of easily extractable alumina, which is possibly a very early product of the weathering of plagioclase felspars and volcanic glasses. Sherman (1962) has proposed that, in the tropics, the weathering system might be reduced to first, the formation of an ionic system, followed by an amorphous system, then a cryptocrystalline system, and finally a crystalline system. The weathering of volcanic ash in the temperate regions has something in common with tropical soil weathering because the nature of the ash material is such that weathering can penetrate deeply, and operates very rapidly at first because the materials are all finely comminuted and crystal surfaces are often broken. If a large amount of ionised alumina is produced during the ionic phase of weathering, this could conceivably have some conditioning effect on the amorphous system, and some of the amorphous allophane subsequently may change directly to crystalline gibbsite during the gradual dehydration of the soils with the onset of summer moisture deficiencies.

Letelier (Letelier and Wright, 1962) considers that the presence of an active alumina fraction in trumao soils is closely related with the comparative infertility of the soils. In many trumao soils, even when the base status is demonstrably high, crop yields are low, and some crops (notably sugar beet) scarcely survive beyond the germination stage unless phosphate is supplied. Although phosphate fixation is unquestionably very high in these soils, it may not be the only factor impeding agricultural use: there appears to be a threshold alumina toxicity which the application of even a small quantity of phosphate helps to overcome in the case of crops sensitive to alumina toxicity, especially if a very soluble form of phosphate is used.

The nature and origin of this active alumina in these trumao soils is still under investigation, but there is a good deal of evidence as to its existence, apart from any effects that might be produced by the exceedingly large amounts of amorphous allophane in the soil. In this case, there is the strong possibility that the presence of ionic alumina is connected with the formation of gibbsite and its existence in the soil simultaneously with the presence of allophane. Seasonal dehydration of the soil would undoubtedly facilitate the formation of gibbsite under these conditions.

The part played by the natural vegetation in the soil system may prove to be a most interesting one. Under natural conditions, there is the usual build up of fertility in the topsoil and the usual formation of rather stable humus compounds, perhaps in conjunction with amorphous allophane. When the forest cover is destroyed, there may be a significant increase in the top-soil and upper subsoil temperatures which promotes an increase in weathering in these horizons, bringing about an increase in exchangeable plant nutrient and some increase in clay formation and transformation. This could happen in an environment where the balance is a very delicate one.

6. Soil classification

In Chile, these soils are regarded as being typical of the group referred to as 'Trumao Soils'. Mella (1958) has studied the micro-structure of trumao soils of this zone, and relates them to the Braulehm terroso in the system of Kubiena (1938; 1956), and to the volcanic ash soils of Spanish Guinea and the Canary Islands (Mella, 1958).

In the current United States system (7th Approximation, ibid) these soils are probably mollic umbrandepts, although the pH valves (as measured in the field) are rather low and no information is available about the carbon-nitrogen ratios.

In the earlier classifications of New Zealand, these soils are weakly weathered Yellow Brown Loams. In the latest New Zealand nomenclature, they are probably alvic soils.

They are close to, but not identical with, the Humic Allophane soils as defined by Kanno (ibid, 1962); the chief divergence being in their lower humus content in the topsoil, their higher base status and higher pH in the upper horizons of the profile.

Provisionally, it is sufficient to regard these soils as allophanic soils developed in a zone of sub-moderate weathering with a marked summer dry season, under a leaching range of slight to moderate, and with but moderate melanisation.

d) Trumao soils of environmental zone 3

This is the zone in which the Chilean allophanic volcanic ash soils have their maximum extension: they may be found from near the coast, across the whole width of the Republic to the frontier of Argentina.

They include many examples of soils derived wholly from subaerial deposits (mainly on the foothills and ranges of the Andean cordillera); some soils derived from volcanic alluvium on the plains of the central lowlands; and many soils derived mainly from volcanic loess, including some near the coast where the loess is possibly derived in part from resorted coastal drift.

The soils are found on a wide variety of landforms ranging from flat alluvial plains, through undulating and gently rolling terraced landscapes, to the strongly rolling downlands of the pre-cordillera of both the coastal and Andean ranges, and the hilly to very steep and mountainous sectors of the Andes. The best agricultural soils, and hence the best known trumao soils, of this zone are those of the plains and downlands, centred about the agricultural region of Temuco, the administrative centre of Cautín Province. There are eleven important volcanic centres in this zone, all on the Chilean side of the Argentinian frontiers, and many of these are still active, giving rise to fresh depositions of volcanic ash from time to time. During the past decade there have been no less than 13 outbreaks of volcanic activity. Usually most of the ash ascends to great heights and is carried by the upper winds far across Argentina, but from time to time fresh ash (very fine volcanic dust) falls on the agricultural land of the central lowlands and may even reach the coast. This dusting of fresh volcanic materials on the agricultural soils is usually very light, seldom more than a few millimetres in depth, but in the vicinity of the volcanoes, it may attain several feet in depth. Areas with fresh ash more than 20 cm in depth are regarded as Recent Volcanic soils and are outside of the Trumao soil category.

The parent materials of the volcanic ash soils in this zone are thus often rather strongly stratified, and there is commonly an abrupt juxtaposition of materials differing widely in mineralogy. Layers of siliceous, pumicetic, rhyolitic ash may alternate with basaltic sand and andesitic ash in some areas; in other areas the dominant parent material is pumiceous gravel and sand; while, even at considerable distances from the volcanoes, an apparently uniform bed of andesitic ash may show strong mineralogical stratification under the microscope. However, all trumao soils appear to contain a high proportion of volcanic glasses, magnetite and various opaque minerals: augite, hornblende, hypersthene and other common volcanic minerals, show a definite pattern that, with more prolonged studies, could certainly be related with specific eruptions from certain of the volcanoes. The precise mineralogical examination of the trumao soils of this zone has scarcely been touched, and it should be attempted because the findings will be of value to the farmers of the region.

1. Environmental characteristics of the zone

Mean annual precipitation ranges from rather less than 1500 mm at the coast, to between 2000 and 2500 over the central lowlands, to over 4000 mm in the central part of the Chilean Andes, and falling again to about 2000 near the frontier with Argentina. The greater part of the zone experiences from four to six weeks when the rainfall averages less than 60 mm per month, and the soils may become dry for two or three weeks; although they are seldom ever as dry as in the preceding zone, unless there is an exceptionally dry year. Even when apparently quite dry near the surface, the subsoils are usually quite moist; moreover, apparently dry topsoil and upper subsoil samples usually give off quite a lot of moisture in the plastic sample bags. Throughout the zone, about 10% of the total rainfall occurs during the summer months, usually in the form of brief showers every few days. Some of the precipitation over the foothills and Andean ranges regularly falls as snow in the winter.

Mean annual temperatures lie in the range 13.5°C to 14.5°C, and mean winter temperatures (July) are about 9.5°C, while mean summer (January) temperatures lie between 21°C and 24°C. Temperature regimes are thus rather similar to those of the Taranaki region of New Zealand, but the summer season in Chile is far drier. The climate of Salem, Oregon, is also slightly similar, but is far colder in winter and somewhat drier in summer.

The natural plant cover of this zone was forest, corresponding to the Nothofagus obliqua-Laurelia sempervirens formation (of Pisano, 1950) on the central lowlands and Andean foothills; with Valdivian coastal forest on the coastal ranges and coastal lowlands; and Valdivian Andean forest in the Andean ranges, including some areas of Araucaria forest at high elevations, and xeromorphic shrub formations, with patches of tussock grassland at altitudes above 1200 m on the drier altiplano uplands near the Argentinian border.

Associated non-trumao soils in this zone are Red Brown Lateritic soils, Brown Forest soils, and Brown Podzolic soils according to Roberts et. al., (ibid, 1958).

2. General soil morphology

Topsoils:- generally slightly shallower than in zone 2, with 12 to 30 cm depth, except in the case of some soils derived from volcanic alluvium where the topsoil may reach 60 cm. A few alluvial trumao soils approach the morphology of Ando soils (Eramao, 1957; Thorp and Smith, 1949);

- textural range generally finer than soils of zone 1 and 2, with silt loams, heavy silt loams and loams predominant, except in soils derived from pumiceous materials, some loessic soils and some alluvial soils;
- colours are predominantly brown to dark brown when dry, being slightly grayish in most alluvial derived trumaos, and often very dark gray in subaerial ash soils at high altitudes in the Andean cordillera; colours when moist are dark reddish brown, to black or very dark brown; notably darker than in zone 2;
- the topsoils are usually slightly firm under natural conditions and show granular or very fine subangular blocky structures, thus differing little from topsoils in zone 2;
- topsoils are somewhat more sticky and plastic, in general, than in zone 2, but this is not very evident unless samples from the two zones are compared simultaneously;
- the lower boundary of the topsoil is usually quite distinct.

Subsoils:- mainly brown grading to yellowish brown when dry; and dark yellowish brown in the lower subsoil when moist, with a marked difference between wet, moist, dry, or moist and crushed, colours: generally a yellow brown dry subsoil changes to very dark yellow brown when moist; to strong brown when moist and crushed; and to dark brown when wet;

- subsoils always show stratification, even in loessic soils, and often this inherited layering of the parent material is very marked with bands of pumiceous material that may be cemented with silica and thus become somewhat reminiscent of 'talpetate' soils (see also, Valencia, 1957);
- textures are mainly silty clay loams to light clay loams in the subsoils of zone 2 trumaos, - ranging from loamy coarse sands and coarse sandy loams in highly pumiceous soils, through sandy loams in some of the trumaos derived from volcanic alluvium, to silty clays in some of the deeper and older ash strata;
- at some level in the upper part of the subsoil there is typically a very friable and loose horizon, structurally similar to the upper part of the trumao subsoils in zone 2, but without the roundish nodules of hardened earth; this light and 'fluffy' material is sometimes 'lumpy' with irregular clods of slightly firmer (slightly hard when dry) nature, but this is not everywhere present; this horizon is often very slow to wet once it has become dry; a very consistent characteristic of the lower subsoil horizon is the development of large shrinkage fissures in drying road banks; these appear to develop during a

particularly dry summer, and to persist through the subsequent autumn, winter and spring; the soil columns separated by the fissures become jointed to form elongated irregular prisms; however, these features are restricted to road banks and do not develop in the nautral soil under forest, nor in the farmed land; the lowest subsoil layers, where the field textures are ever more clayey, do not develop shrinkage cracks in the road cuts and presumably other clays besides allophane are appearing in these older materials;
- subsoils are usually slightly sticky and sometimes more than moderately plastic, - an advance in both properties over similar horizons in the trumao soils of zone 2.
- the 'slipperyness' and 'greasyness' characteristic of allophane clays in the moist condition, is very distinctly developed in this zone; almost all subsoil (and topsoil) materials show this characteristic, - even many of the highly pumiceous soils;
- many of the subsoil horizon boundaries are very distinctly or sharply defined, indicating that they often coincide with inherited stratification features.

3. <u>General chemical characteristics</u> (see tables 6a and 6b)

A good deal of the essential chemical information needed to characterise adequately the trumao soils of zone 3 is still lacking. Most of the necessary soil samples are in the hands of the Ministry of Agriculture and will probably be available in due course. Only four profile analyses are presently available.

Topsoils:- No mineralogical analyses are available for the trumao soils of this zone, and fusion analyses of the clay fraction are available in the case of only one soil, and that soil is derived mainly from alluvial and loessic volcanic materials (table 3b).

<u>Natural topsoils show</u> -

- slight to moderate acidity (pH 5.3 - 5.7);
- high organic matter content (25% and over);
- very high base exchange capacity (59 - 75 m.e.%);
- exchangeable calcium is lower than in the natural trumao topsoils of zone 2, ranging from 3.6 to 15.9 m.e.%;
- base saturation much lower than natural topsoils of zone 2 trumaos, with a range between 7.2% and 27.4% (i.e. very low to low).

<u>Natural subsoils show</u> -

- a gradual rise in the pH with depth, but the range is from moderately acid to approaching near neutral (pH 5.1 to 6.5);

- decreasing organic matter content with depth, but even at 1 metre there is often more than 3%, (range 2.2% to 21.3%, i.e. low to - high);
- cation exchange capacities between 48 m.e.% and 71 m.e.%, which lies mainly in the 'very high' category of Metson (1961);
- exchangeable calcium ranges from 2.9 m.e.% to 9.8 m.e.% (low to medium) and decreases with depth, except in the case of the single sample from volcanic alluvium where the influence of a seasonal watertable is evident;
- base saturations range from 4.7% to about 17%, which is in the very low category.

Observations - Apart from the single sample from alluvial volcanic materials, all the data are for trumaos of mainly subaerial origin; and all are from soils under their natural, undisturbed conditions. No data for farmed soils is yet available.

The natural soils have a consistently very high cation exchange capacity and are poorly supplied with exchangeable bases. The fertility status of these soils, on the measure of base saturation, is decidedly lower than the trumao soils of zones 1 and 2. In addition, these soils have typically a very high rate of phosphate 'fixation' (Schenkel, pers. comm. 1962), at times up to 90% of the added phosphate becomes rapidly transformed into phosphate compounds that are not available to plants. No information is available concerning the total nutrient reserve available in these soils: casual microscopic observations showed the presence of hornblende, hypersthene, and occasional crystals of augite and quartz in most soils, but relatively few felspathic minerals were seen. Magnetite was noted in abundance in all soils.

On the evidence available, it is considered that these soils are slightly more weathered, and (mainly) very much more leached than comparable trumao soils of zone 2. Although physical analyses for textural determinations are generally unreliable in these soils, the 'clay fraction' determined is usually up to 20% higher in the trumao soils of zone 3 as compared with equivalent soils of zone 2. Soil temperatures taken in summer at various depths show that the mean soil temperatures are little different from those for trumao soils of zone 2, for comparable depths and under equivalent kinds of vegetation. The soils are, however, much moister during the summer in zone 3. Provisionally, the trumao soils of zone 3 are considered as moderately weathered allophanic volcanic ash soils.

4. <u>Characteristics of typical soils</u>

In this zone there are an abundance of examples of soils derived mainly from subaerial volcanic materials; many soils derived in part from subaerial materials mixed with volcanic loess; a good range of soils from volcanic alluvium; some wholly loessic soils with volcanic minerals dominating their composition; and Trumao-Recent Volcanic Ash intergrades. Soils derived from pumiceous rhyolitic ash are fairly abundant in the Andean cordillera, From this wealth of material, seven soils will be described in detail in the Appendix: three of these soils belong to the 'mainly subaerial material' category, and they are included mainly to illustrate that these soils show consistent features that are distinctly different from those of equivalent soils in zone 2 (the Santa Barbara soils). In Chile, it has been the custom to regard all these soils of zones 2 and 3, as belonging to one common soil association: however both the field evidence, and the laboratory evidence - as far as it goes at present - , indicate that the trumaos of zone 3 are sufficiently different to warrant their separation as a separate association. The name of CAUTIN has been provisionally adopted for this association, since these soils are the characteristic trumao soils of Cautín Province.

i) Cautín silt loam (Appendix profiles Nos. 21, 22, 23)

Soils of the Cautín association have the following profile characteristics:-

15, 20 or 25 cm dark grayish brown to dark brown silt loam, slightly firm, and finely blocky or granular. (field pH, 5.8; lab. pH, 5.3);

20 cm brown silt loam, usually friable to very friable, fretting away easily in road banks, very finely granular or crumbly, but sometimes 'lumpy'. (field pH, 5.4; lab. pH, 5.1);

60 cm strong brown or yellowish brown silty clay loam with a coarse blocky structure, often quite firm, and often with prominent shrinkage cracks on exposed road banks showing an irregular prismatic type of structure. (pH in field, 5.8; in lab., 5.5);

40 cm yellowish brown heavier silty clay loam, grading to silty clay, less tendency to form shrinkage fissures and more plastic. (field pH, 5.8; lab., pH 6.0),

On.. various layers of stratified volcanic ash, including some rather compact, weakly cemented pumiceous layers and thick beds of yellowish brown to brown very plastic silty clay.

This soil is normally developed over strongly stratified ash beds and shower layers, and in some areas the pumiceous layers are slightly cemented, probably with silica.

Farming on these soils is mainly a rotation between pasture and wheat cropping, with wide differences in the length of rotation adopted by individual farmers. Nitrogen and phosphatic fertilizers are regularly used with the cereal crops. Sometimes potatoes, flax or sugar beet are used as the first crop on land out of pasture, and occasionally two crops of cereal (wheat, oats or barley) are grown in succession. On some rented farms, cereals are grown in continuous succession, but these farms change owners with great frequency, and some are in a very run-down condition. The chief limiting factor to production with cereal crops and sugar beet is clearly the problem of unavailability of phosphate in the soil; pasture production is also affected by this factor, but it shows mainly in the difficulty of maintaining the legumes in the sward. Properly managed and carefully fertilized, these soils make excellent dairy pastures, and carrying capacity is limited mainly by the amount of summer feed available for livestock. In some areas local irrigation systems have been contrived, and results are often excellent. Although the soils are seldom completely dry under natural summer conditions, nevertheless the high water holding capacity of the allophane clays induces a period of physiological dryness which sharply diminishes pasture production during about three of the summer months. Irrigation removes this obstacle to farm production in a spectacular way.

ii) Icalma loamy coarse sand (Appendix, profile No.24)

This soil is included because it forms a sharp contrast in soil morphology owing to the very high proportion of rhyolitic pumiceous ash in its parent material. It is developed under rather similar rainfall conditions (about 2000 mm rainfall per annum) but at an elevation of nearly 800 m higher in the Andes, where mean annual temperatures are somewhat lower (13.5°C as against 14.5°C) and some of the winter precipitation falls as snow. The natural vegetation on this soil was Araucaria forest.

The profile shows:-

30 cm black loamy coarse sand, slightly firm but with a blocky structure;
25 cm dark brown loamy coarse sand, rather friable and with a much finer (granular) structure;
25 cm brown to dark yellowish brown coarse sandy loam with many large lumps of weathering pumice;
90 cm yellow to pale yellow firmly packed pumice gravel of rather coarse size;
40 cm very dark gray brown coarse sandy loam, - an old buried topsoil horizon;
20 cm dark grayish brown slightly gravelly sandy loam, rather massive in appearance,
On... strong brown gravelly sandy loam, and various other highly pumiceous strata continuing to over 5 m.

Soils of this type cover a considerable area of the altiplano uplands of Malleco Province, and are also found on many of the steep slopes of the central cordillera. They are quite stable under the natural forest, and, with care, even quite steep slopes can be cleared and established under a grazing regime, but, in the majority of cases, the forest is simply milled and the trash burned, leaving volunteer grasses as the basis of the grazing pastures. Under these conditions quila bamboo and coligüe bamboo (Chusque spp.) invade the hillside, and frequent burning is carried out to control these plants. Under this type of management, erosion inevitably accelerates to the point where the underlying pumice horizons in the soil are exposed; and once this occurs over a wide area, farming becomes almost impossible. In severe cases, great landslides may occur, burying the more manageable soils of the lower slopes in a thick mantle of loose pumice stones.

No chemical data is yet available for this soil, but they are expected to be slightly to moderately acid, yet far better supplied with phosphate in available form than the trumao soils of the lowlands and foothills, and with a much higher base status generally. Good farmland could be developed on these pumice soils, but some prior experiments with fertilizers and seed mixtures should be undertaken before farmers are encouraged to enter the area. In so many of the more remote districts of Chile, colonisation is permitted ahead of scientific appraisal of the soil resources.

iii) Vilcun loam to silt loam (Appendix, profile No.25)

Vilcun soils are developed on flattish terrace land to the north of Temuco; they are underlain by various kinds of old valley fill, and part by old breccia flows from the Andean cordillera. In this latter situation they are somewhat similar to Victoria soils of the Malleco Province. Vilcun soils are from 80 cm to 1.5 m deep above the consolidated substrata, and the main soil material is rather mixed volcanic alluvium. They are developped under about 2200 mm mean annual rainfall, with about one 'dry' month in the summer. The natural plant cover was mainly roble forest, with lingue, canelo, etc.

A typical soil profile shows:-

30 cm dark grayish brown loam with a strong silt component, slightly firm, and with a strong but fine structure;
30 cm brown, faintly yellowish brown, very fine sandy loam that is friable and has a weak blocky structure;
30 cm distinctly yellowish brown fine sandy loam with some small rounded river gravels, usually very friable in this horizon, but not prominently structured;
30 cm yellowish brown gravelly loamy sand, often quite compact and lightly cemented,
On.. rather less compact gravelly loamy sand and gravelly sand.

This is one of the best agricultural soils in the Cautín Province, and has the additional advantage that it is comparatively easy to place under irrigation. Chemical analyses show that there steadily improving base status with depth; nor are the soils very markedly acid. Phosphate fixation is, however, likely to be quite high and all farmers on this soil employ phosphatic fertilizers as well as nitrogen. Some also regularly use potassic fertilizers, although the subsoil potassium status is not too low.

This soil is used mainly for cropping (wheat, oats, flax, rape-seed; sugar beet can also be grown) but very good productivity can be achieved with permanent dairy pastures, and with clover crops grown for seed.

iv) Temuco silt loam (Appendix, profile No.26)

This second soil derived from volcanic alluvium is included by way of comparison with Vilcun soils. The profile quoted at length in the Appendix is rather deeper than normal for this soil, which usually ranges from 20 cm to 45 cm in depth, but shows about the same sequence of horizons and strata.

Temuco soils are also developed on river terraces in the vicinity of Temuco city, and on similar terrace lands further to the south. Their relief is flattish to very gently undulating. They are developed under about 2000 mm annual rainfall, with slightly over one dry month in an average year. The substratum of these soils is often river gravel, and where the volcanic alluvium is shallow above these gravels, the soils are subject to summer drought conditions, far in excess of one month. This makes little difference where the soils are under irrigation, but seriously limit their use in areas where no irrigation is available.

A typical soil profile (not that given in the Appendix) shows:-

20 cm grayish brown silt loam, friable and with a weakly developed fine blocky structure, this horizon often contains fragments of fine pumice;
20 cm yellowish brown (10YR 5/8, moist) slightly gritty heavy silt loam with very fine pumice fragments, slightly firm, and with a well developed fine blocky and granular structure;
15 cm tightly packed medium pumice gravel showing some horizontal bedding;
10 cm dark yellow brown, rather compact loamy sand,
On.. large rounded river gravels.

Temuco soils appear to have about the same level of fertility as Vilcun soils, or perhaps slightly lower, and their productivity is mainly related to the soil moisture supply and availability. In places where these soils are adequately irrigated, supplied with phosphatic and nitrogenous fertilizers, yields are often as good as on Vilcun soils. In places where the pumice layer is well developed in these soils, water may be slow to penetrate from the upper into the lower subsoil when the water is first applied. In places where the underlying gravels, or other old alluvial beds, are consolidated and interbedded with silty clay, drainage control should take precedence over irrigation construction works, for under these conditions the shallower phases of Temuco soils are easy to waterlog, and adequate drainage is of first importance.

v) Trevolhue very fine sandy loam

Trevolhue soils are developed over a rather limited area, near the coast and along the north bank of the Imperial river, in Cautín Province. They are almost certainly derived from volcanic loess. They are developed under about 1900 mm mean annual rainfall, on gently to moderately rolling landscapes, and their original plant cover was roble forest with a wide variety of evergreen broadleaf species, including some that are typically coastal forest especies.

A typical profile shows:-

20 cm dark brown friable very fine sandy loam with a very distinct fine granular structure;
25 cm yellowish brown, rather heavy, silt loam, also friable and less well structured than the first horizon;
30 cm yellowish brown silty clay loam, even more friable than the first two horizons, and showing vertical shrinkage cracks in drying road banks,
On.. reddish brown clays of the 'Collipulli' type.

In places Trevolhue soils are much deeper than 1 metre, and in some small areas they are less than 40 cm deep. Almost everywhere they are underlain by 'red clays' (the "Rojos Arcillosos") of the Chilean pedologists (e.g. Besoain, ibid 1958) which are very old volcanic ash, probably loessic, materials that have matured to the point where the allophane has become transformed to halloysite and kaolinite. These under-beds are usually compact and plastic clays.

Trevolhue soils are expected to be slightly acid to nearly neutral in reaction, to have rather lower cation exchange capacities than the rest of the Trumao soils of the zone; to be rather well supplied with calcium, magnesium, potash and sodium in exchangeable form; and to have a rather higher base status than most of the other trumao soils. Their main agricultural limitations will be their high phosphate 'fixing' powers, relatively low nitrogen and humus content, and, particularly, summer dryness. This latter factor certainly limits pasture production on these soils (the shallower phases are not so much affected because the underlying red clays approach nearer the surface) and is due to the fact that this part of Cautín Province has a rather longer drought period in most of the years. They are situated in a high position above the Imperial river and hence cannot be readily irrigated.

5. Soil genesis

Both weathering and leaching have increased in intensity in the soils of zone 3, and there is a marked advance also in the intensity of topsoil melanisation. The majority of trumao soils no longer show the nodular aggregations of earth in the upper subsoil, although this horizon often remains very friable and inclined to fret away in exposed road banks. One feature, which was becoming apparent in the southern facies of trumao soils of zone 2 (see Appendix profile No.18) - the tendency for the lower subsoil horizon to form shrinkage cracks in road banks - is much more strongly developed in zone 3. This is attributed to the fact that these subsoil horizons are normally fairly moist all through the year in their natural condition in zone 3, and when exposed and allowed to dry out more sharply in a road bank, the allophane progressively shrinks, and after drying out never regains its former turgid condition. The development of these shrinkage cracks is accompanied by the appearance of prism-like aggregated in the vertical columns between the fissures: neither the prisms nor the vertical fissures can be clearly seen in pits dug in the landscape, unless the pits are also left open for a complete summer, whereupon similar structures begin to appear in the walls of the pits. This irreversible drying of the subsoil materials is similar to that reported from Hawaii (Cline, 1955; Sherman, 1952) and Samoa (Wright, 1963), where the soils involved are Hydrol Humic Latosols. When material from these dry Chilean road banks is thrown into water, the smaller peds float for a time and then suddenly slake and appear in the water as a suspension of fine silt particles.

We have as yet no clay analyses to confirm that these trumao soils have less gibbsite (or no gibbsite) than the trumao soils of zone 2. It is possible that, since there is less seasonal drying out of the soil, gibbsite crystalisation does not occur, except in the deeper subsoil layers. In two cases, small 'waxy' nodules have been noted in the silty clay strata at about 2.5 m below the surface; on analyses (Birrell, pers. comm., 1961) these proved to be gibbsite. In both these cases, the gibbsite accumulation was associated, not with allophane-dominated material, but with materials that had all the field characteristics of kaolinitic and halloysitic clay (Taylor and Pohlen, 1962).

In many of the trumao soils of this zone there is clear evidence of clay movement: clayskins and clay flows appear weakly at about 35 cm below the surface, and appear more strongly in the 50-80 cm layers of the subsoil. Below this depth, they are sometimes combined with pressure effects between the peds, and in the deepest subsoil layers these pressure 'faces' are often the dominant feature. In none of the trumao soils are true horizons of clay accumulation visible; sometimes there is a horizon of apparent clay accumulation, but closer examination has invariably shown that this feature is connected more with the inherited pattern of stratification and the age of the soil material, than with any acquired characteristic resulting from mass clay movement and accumulation. The presence of clayskins testifies to the fact that there is <u>some</u> clay movement, but it is not anticipated that this is of a very high order.

In much the same way, base status analyses indicate clearly that the trumao soils of zone 3 are more leached than those of zone 2, yet there is little enough expression of this in the soil morphology. Not only is the base saturation % low because the cation exchange capacity is very high, but the total amount of exchangeable bases is quite low. If these soils had been formed from more normal parent materials, lower in volcanic glasses and richer in quartz, the modal profile for this zone might easily have been something akin to an Acid Brown Forest soil, in which the moderately strong impress of the leaching processes would be displayed distinctively in the soil profile morphology. Unfortunately, no such types of soil parent material occur in the zone: all are to a large degree contaminated with volcanic minerals (see also Leon, 1962).

Although the trumao soil group are undeniably very difficult to evaluate in respect of the operation of weathering and leaching processes, it is provisionally considered that the trumao soils of zone 3 represent at least moderately weathered soils, and the range of leaching extends over moderate to strong: the moderately leached representatives being the loessic trumaos near the coast, the moderate-to-strongly leached soils being those of the lowlands and foothills, and the more strongly leached representatives being found near Cunco, near Cherquenco and near Lonquimay.

In these last mentioned localities, farming experience indicates a very low base status in the soils, but the actual soil profiles show little morphological support apart from an increased crispness of the subsoil aggregates, slight increase in clayskin development, and a very marked increase in topsoil melanisation. Some of these soils have almost the morphology of Andosols, and almost exactly correspond to Kanno's (ibid) descriptions of some Humic Allophane soils. In some of these Chilean Humic Allophane soils, the pH range lies between 5.0 and 5.3 and never climbs above 5.4 unless there is a recent dusting of fresh volcanic ash on the soil surface.

Melanisation, in comparison with the full range of allophanic volcanic ash soils available in Chile, can be characterised as being moderate-to-strong in the trumao soils of zone 3. As would be expected, there are minor local variations in the intensity of melanisation which can be correlated with the nature of the plant cover, or with the history of ecological change in the area. For example, trumao soils that have been uninterruptedly under roble forest are usually less melanised than the same soils that have been cleared 50 to 80 years ago and allowed to revert to scrubby vegetation. Trumao soils in which bracken fern has become established are also notably more deeply melanised than surrounding soils without this invader.

6. Soil classification

In Chile, these soils are regarded as good examples of the Trumao soil group, and no doubt they would also fall within Kubiena's category of Braulehm terroso. Mella (pers. comm., 1963) is currently investigating the micropedology of the trumao soils of this zone in Professor Kubiena's laboratory in Germany.

In the current United States system (7th Approximation, ibid) they are perhaps intergrades between Umbrandepts and Ochrandepts, closer to the former than the latter; or perhaps no more than mollic umbrandepts of a rather lower base status than usual.

In the earlier classification of New Zealand, these soils would have been called moderately to strongly leached, moderately weathered Yellow Brown

Loams. They would now be referred to as 'moderately-to-strongly enleached, weakly clay illuvial alvic silt loams from moderately argillised andesitic and rhyolitic ash'. This would bring them very close to the Otorohanga silt loam, a soil which they closely resemble both in farming characteristics, some chemical characteristics and in many morphological characteristics.

In a great many respects they are coming close to the group characteristics set down by Kanno (ibid, 1962) for the Humic Allophane group, yet many soils are not quite within this group as defined by Kanno.

Provisionally, it is sufficient to recognise them as allophanic soils developed in a zone of moderate weathering, with a very weakly indicated summer dry season, developing under a leaching range of moderate to strong, and with moderate to strong melanisation. The strongly pumiceous members of the group need separate recognition, but they are still soils in which allophane dominates most of the soil properties, even though the total amount of clay in the soil is likely to be small. Thus in this zone, it is advisable to append the phrase '... developing from rhyolitic pumiceous ash' or '... developing from andesitic ash' etc., in the above identification.

e) Trumao soils of environmental zone 4

In this zone trumao soils are restricted to the steeplands and foothills of the Andes, and to a relatively narrow strip of downland and well-drained terrace lands. The main lowland area of the central vale is occupied by poorly drained terraces with ñadi soils.

The great majority of trumao soils in this zone are derived directly from volcanic ash deposits; only on some of the terraces do soils of loessic or alluvial origin appear. The subaerial ash mantle in the Andes cordillera region is exceptionally deep; several profiles exceeding 8 metres in depth were measured and recorded, and there is little diminution in depth even on the steeper slopes. Such thick layers of ash appear to remain surprising stable so long as the natural forest is not seriously tampered with. The ash beds and shower horizons decrease in depth but multiply greatly in n number of distinctive strata on nearing one of the volcanoes in the zone. There are about seven important volcanic centres in the zone. The actual cones of most of these volcanoes are covered in recent volcanic ash, often buried under several feet of snow, except in the height of the summer.

The parent materials vary widely in nature, and strata of very different mineralogy may follow each other in succession. This was also a feature of zone 3; the most obvious difference is perhaps the rather more common appearance of finely divided pumice fragments in the fine ash beds of zone 4. These can be seen with the naked eye in most soils as very fine whitish speckling amongst the brown or yellowish brown subsoil materials.

Little precise mineralogical information is available about any of the main soil forming ash beds or shower layers in this zone, yet it is a field that is not without significance to farming.

1. Environmental characteristics of the zone

Apart from the landform and parent material characteristics just described, the environment of this zone includes a climatic regime in which upwards of 2000 mm of rain falls on the main area of trumao soils, except for a somewhat drier local region around Osorno where the mean annual rainfall is in the region of 1500 mm. In places, over the Andean cordillera, the rainfall rises to over 5000 mm. From 12% to 16% of the total rain falls in the summer months, so that the seasonal distribution of the rainfall begins to approach more closely the conditions of New Zealand volcanic ash soils. In this zone of Chile, around 40% falls in the winter months; rather more than 25% falls in the autumn period; slightly less than 20% falls in the spring period, and the rest is summer rain, - usually several showery days are followed by several fine days. The soils are seldom really dry at any time of the year; most subsoils are never truly dry.

Mean annual temperatures lie between 11°C and 12°C over the lowlands, but the annual temperature mean is much lower in the Andean ranges. On the lowlands the mean summer temperatures lie between 14°C and 17.5°C; mean winter temperatures are between 7°C and 8.5°C. Some snow may fall in winter but is of very short duration on the lowlands; snow lies for upwards of two months on some of the higher foothills, and considerable longer at higher altitudes.

Most of the zone does not experience any 'dry' month in normal years, apart from a small region in the immediate vicinity of Osorno city which may go for six to eight weeks without significant rainfall.

The closest climatic analogues to this zone are perhaps to be found in the province of Nelson in New Zealand and parts of Westland Province (e.g., Greymouth) although the regime in New Zealand is slightly drier in winter and slightly wetter in summer. Unfortunately, volcanic ash soils are not known from these New Zealand localities (see Gibbs, 1950).

The natural plant cover over much of this zone (apart from the semi-swamp forests of the ñadis) was roble forest with a high proportion of canelo, laurel, ulmo, olivillo, quila, and coligüe; the proportion of the evergreen species increases in the foothills, with coigüe gradually emerging as the dominant tree in many parts. At the highest altitudes, ñirre is often the only tree in the forest, but the tree line is projected upwards by a host of small shrubby plants, including many Ericaceae and Berberidaceae, often to the limit of perpetual snow.

Associated non-trumao and non-ñadi soils in this zone include Red Brown Lateritic soils (Roberts and Díaz, ibid, 1959), Acid Brown Forest soils, Podzols, and Podzolized Gley soils.

2. General soil morphology

Topsoils:
- generally about the same depth (12 to 30 cm) as in zone 3 over the lowlands and outer foothills, but deepening markedly towards the interior of the Andean cordillera;
- colours definitely darker than in zone 3, being always very dark brown to black when moist (except in the case of some loessic and alluvial volcanic ash soils on the terraces near Osorno and Valdivia cities),where they are less dark brown; and except in the case of forested topsoils deep in the Andes where they may be very dusky red to very dark reddish brown and somewhat peaty;
- thus deep and dark topsoils characteristic of the Ando soils are not common on the lowlands but increase in frequency towards the Andean ranges; most of the "Ando soil profiles" are somewhat pumiceous; textures vary widely, ranging from silt loam (very common on the lowlands plains and downlands)to loamy coarse sands (mainly in the pumiceous soils of the Andean ranges);
- structures are generally more clearly defined than in zone 3, and many of the peds have a decided 'crispness'; granular structures predominate;
- topsoils are usually friable when broken, but often slightly firm in the mass; they are somewhat more compacted in nature than those of zone 3, but are seldom sticky or more than very slightly plastic; the lower limit of the topsoil is often less distinct than was the case with topsoil horizons of zone 3.

Subsoils:
- moist subsoil colours range between brown and yellowish brown in general with some soils showing a slightly redder hue, yet seldom achieves more than strong brown (7.5YR 5/6); in the interior of the Andes, the whole profile may be dark brown when moist, with the exception of included pumiceous strata which are more usually brownish-yellow to pale yellow;
- subsoils are always stratified, often very strongly; but in zone 4 it is less common to find deeper pumiceous strata in a semi-cemented condition; buried topsoils are not uncommon, and in a few cases fine charcoal fragments have been noticed in the upper part of these buried topsoils; no carbon 14 dating results have been received yet from this material;
- textures range widely, having an approximate mean texture of heavy silt loam or loam, in a range of loamy sand to clay loam; most subsoil horizons and layers are fairly firm, and in most cases there is no very loose and powdery upper subsoil horizon as occurs in many soils of zone 3, and almost all soils of zone 2; some degree of stickyness and considerable plasticity is evident in all but the most pumiceous subsoil materials;

- the subsoil shrinkage cracks, so characteristic of many trumao soils in zone 3, are but weakly developed in zone 4, and are often absent from trumao soils (but are very conspicuous in ñadi soils that have been allowed to dry out); blocky and granular structures are common in the subsoils, but irregular prismatic structures are rare; the characteristic allophane 'slipperyness' and 'greasyness' in subsoil materials is very easy to detect in all but the most pumiceous soils;
- soil horizon boundaries are often coincident with inherited layer boundaries, and are thus frequently distinct or even abrupt.

3. General chemical characteristics (see tables 7a, 7b and 7c)

Chemical data is largely lacking for the trumao (and ñadi) soils of this zone. A considerable number of samples are still awaiting examination. Three profiles with base status data are available; two horizons only with fusion analysis of the clay fraction; and two with some mineralogical data for the sand fraction.

On this basis it is impossible to describe the general chemical characteristics of these soils, and expansion of this section will have to be defered until further data becomes available.

4. Characteristics of typical soils

In the Appendix will be found detailed descriptions of eleven soil profiles selected as representative of this zone. They are mainly soils derived from subaerial ash materials, and include soils developed in rhyolitic pumiceous ash, fine and coarse andesitic ash of intermediate mineralogical composition, and one from more basic andesitic ash. By way of comparison two soils derived from mixed loessic and alluvial materials are included.

Puerto Octay soils are representative of the type of profile developed along the margin of the lowland plain, and Puerto Fonck soils are developed on equivalent rolling downland at the start of the Andean foothills, under a slightly wetter and perhaps colder climate; Puyehue soils are developed further in the foothills on strongly rolling to hilly slopes, but from ash materials not greatly different from Puerto Fonck and Puerto Octay soils; Choshuenco soils are similar to Puyehue soils but developed from more basic andesitic materials; Rupanco soils are developed in acidic rhyolitic sands and pumiceous ash, and show many profile characteristics similar to the Andosols; Quillelhue and Pucón soils are likewise formed from rhyolitic pumiceous ash and are very similar to some Yellow-brown Pumice Loams of New Zealand; while Osorno and Pelchuquin soils are derived from much more mixed volcanic materials and are partly loessic and alluvial in origin.

i) Puerto Octay silt loam, and fine sandy loam (Appendix profiles No.28 and No.29)

This soil is the main trumao farming soil in zone 4, apart from Osorno soils. Puerto Octay soils occur over a strip of gently undulating to rolling land, approximately 200 km in length but in places less than 10 km wide, along the inner margin of the lowland plains and terraces, in the Provinces of Llanquihue, Osorno and Valdivia. It is developed under about 2000 mm annual rainfall, at elevations between 100 and 300 m.

The profile is moist under natural conditions and shows:-

15 cm black or very dark brown silt loam or very fine sandy loam, quite friable and well structured;
25 cm dark brown, brown, or strong brown silt loam to sandy loam, friable and rather less closely knit than the surface horizon;
20 cm dark brown or strong brown tending slightly to yellowish red silt loam, distinctly friable but usually more plastic than the previous horizons;
60 cm dark brown or brown silt loam or sandy clay loam, usually fairly firm to very firm but often less plastic than the horizon immediately above;
20 cm dark yellowish brown, strong brown or brownish yellow silty clay loam to clay, more friable than last horizon but more plastic,
On.. rather compact substratum, distinctly clayey but often gravelly as well.

The substratum varies considerably in composition, but usually is formed of peri-glacial alluvial materials, with occasional large included angular boulders.

Farming on these soils is mainly a short rotation between dairying or fattening pastures and arable crops of many kinds, including potatoes, flax, sugar-beet, oats, rape-seed, and mixed vegetable crops. Nitrogen, potash, phosphate and boron are frequently applied as soil amendments, and some farmers use lime as a regular part of their farm management programme. The soils are usually slightly acid under natural conditions and many farmed soils have been brought to a near-neutral condition. Probably not all the applied fertilizer is needed to maintain production (except phosphate, which is certainly very necessary) but farmers are content that their fertilizer programme does give economic returns. Fertilizer salesmen are particularly vigorous in this area. The topsoils remain dark and well floculated under this quite intensive form of soil use, and appear to maintain their humus content very well.

ii) Puerto Fonck very fine sandy loam, and silt loam (Appendix, Nos. 30, 31)

Puerto Fonck soils grade gradually into Puerto Octay soils along their western limits, and into trumao soils with deeper and darker topsoils along their eastern limit. The average width of their belt is perhaps 10 - 15 km, and they are developed on rather more strongly rolling landscapes than Puerto Octay soils. Probably they experience a rainfall of about 2500 mm, and are nearly always slightly moist to wet in the natural condition.

The profile shows:-

30 cm very dark brown to black fine sandy loam or slightly peaty silt loam, friable and well structured, but neither sticky nor plastic;
40 cm very dark yellowish brown or dark reddish brown loam to fine sandy loam, usually friable and becoming slightly sticky and plastic;
40 cm dark yellowish brown to yellowish brown silt loam to loam that may contain small fragments of pumice, and is slightly sticky and moderately plastic as a rule;
80 cm dark yellowish brown sandy or silty clay loam, usually quite friable and well structured, sticky and plastic,
On.. substratum of rather compact clayey glacial materials or alluvial materials containing glacial debris.

Farming on these soils is similar to Puerto Octay soils but the more strongly rolling topography imposes some restriction on cropping; a higher percentage of these soils is maintained in pasture, some permanent pasture and some under long rotation with arable crops. More oats is grown on these soils than on Puerto Octay soils and less fertilizers are applied as a general rule. The very dark topsoil colours persist in farmed soils. In general, the field pH is very slightly lower in Puerto Fonck soils than in Puerto Octay soils.

iii) Puyehue silt loam (Appendix, profile No.32)

Puyehue soils are found along the inner (eastern) margin of many Puerto Fonck soils, and are developed on very strongly rolling and hilly landforms as a rule. Much of this soil is still covered with natural forest, or with secondary forest and reverted shrubland..

The soil profile shows:-

40 cm very dark brown to black friable, well-structured, silt loam that is slightly sticky and plastic;
50 cm very dark brown slightly firm silt loam, rather conspicuously granular and slightly sticky and plastic;
60 cm very dark brown to brown friable silt loam, well-structured, slightly sticky and slight-to-moderately plastic, and with an abundance of fine black mineral particles;
40 cm dark brown loam, slightly firm but very well structured, neither sticky nor plastic;

60 cm dark brown heavy loam, slightly firm, slightly sticky and plastic,
On.. brownish stratified ash beds and shower materials, mainly loams to clay loams, some distinctly pumiceous.

It is difficult to assess the agricultural potentialities of this soil at the present time because few long-established farms exist on these soils. It would appear that many farmers find that they can maintain permanent pastures without the use of fertilizers although one would expect that cloversat least would benefit from applicationsof phosphate. The pH of the soil is around 6.0 on both farmland and under the natural forest. Relatively little cropping is carried out on Puyehue soils at the present time, and yields are said to be no worse than on Puerto Fonck soils in the case of oats, although there is usually some loss of grain due to weather problems during the harvest season.

iv) Choshuenco sandy loam (Appendix, profile No. 33)

Choshuenco soils are similar in some respects to Puyehue soils being generally dark in colour throughout the profile, but they have a more reddish hue (5YR as against 7.5YR) and more sandy textures. An important component in their parent materials is black basaltic and basic andesitic sand ejected from nearby Choshuenco volcano.

The soil profile shows:-

25 cm very dusky red to black, distinctly peaty, sandy loam that is friable very well-structured, and neither sticky nor plastic;
20 cm dark reddish brown grading to very dark grayish brown gravelly loamy sand with occasional scoria fragments, rather poorly structured, and neither sticky nor plastic,
On.. repeated layers of fine and coase sandy loam and loamy sand, some distinctly scoriaceous; general colour dark reddish brown to brown; seldom more than very slightly sticky or plastic.

Much of this soils is still under the natural forest but where it has been cleared, excellent spontaneous pastures develop, usually with volunteer clovers. A few cases were seen where farmers has experimented with fertilizers on these pastures; there were some noticeable responses to nitrogen and phosphate, especially clover responses to added phosphate. Choshuenco soils are found mainly on hilly to very strongly rolling relief, and are developed under a rainfall of about 4000 mm per annum, - both factors severely limit soil use to permanent pasture production. Hereford cattle appear to do especially well on these soils.

v) Rupanco gravelly coarse sandy loam (Appendix, profile No. 34)

Rupanco soils are located mainly near the head of Lake Rupanco on lakeside bench terraces; although rather similar soils have also been noted in similar situations at the head of lakes Villarrica and Calafquen. The parent material is markedly pumiceous and appears to be mainly subaerial in origin, although slightly resorted by water. They do not appear to be true lake sedimentary deposits, so much as very heavy subearial deposits that suffered some colluvial movement or additional floatation after being emplaced. They occur on rolling to flattish landforms under a rainfall that is probably of the order of 3500 mm per year. Some of these soils are still under natural forest.

The soil profile shows:-

45 cm black gravelly coarse sandy loam that is friable, quite well structured, non-sticky and non-plastic;
20 cm very dark brown gravelly loamy sand, rather firm and with visible grains of pumice;
85 cm strong brown firmly packed coarse pumiceous gravel;
45 cm brown sandy clay loam, slightly firm and with occasional softened, weathering pumice lumps,
On.. dark yellowish brown gravelly sandy loam with many weathering pumice fragments.

Rupanco soils are mainly occupied by small farmers belonging to 'Colonias' established by the Caja de Colonisación of the Chilean Government, or are within Forest Reserve areas. They are cropped occasionally with oats, but are more usually occupied by natural pastures which are quite notable for the growth of white clover, also a volunteer plant. They are not topdressed or fertilized, and appear to maintain their fertility well under their present farming regime. They are said to grow excellent crops of potatoes and household vegetables. They are likely to be of relatively small total extent.

vi) Quillelhue loamy sand (Appendix profile No. 35)

Quillelhue soils are developed from pumiceous volcanic ash of wholly subearial origin, at the foot of Lanin volcano near the Argentinian border, in the upper reaches of the watershed of the Minetué river. They are approached through Villarrica and Pucón, in the province of Cautín. They are mainly under natural forest and first appear at an elevation of about 700 m.

The soil profile shows:-

15 cm dark reddish brown loamy sand, very friable, but well-structured;
20 cm very dark brown loamy sand with some pumice fragments, slightly firm and rather poorly structured;

80 cm yellowish brown tightly packed pumice gravel of rather coarse size;
100 cm dark yellowish brown slightly gravelly, heavy sandy loam grading to coarse sandy clay loam, that is firm but not particularly well-structured,
On.. alternating beds of coarse and fine pumiceous ash.

Quillelhue soils are found only on very strongly rolling to hilly and steep relief and farming operations are confined to the efforts of small 'Colonia' farmers and illegal squatters. Cleared land is occupied mainly by natural volunteer pastures, clovers and weeds, and these are ploughed up and sown from time to time in oats and wheat, or potatoes. Fertilizers are not used on these soils, but phosphate would probably prove beneficial, even in very small quantities. From the evidence available (see table 4b) the base status is rather low (18%) but the cation exchange capacity is also low and small amounts of fertilizers would be expected to give a worthwhile response. The soil pH increases from slightly acid in the topsoil to neutral in the subsoil.

vii) <u>Pucón coase sandy loam</u> (Appendix profile No.36)

Pucón soils are developed in much the same type of parent material as Quillelhue soils but at greater distances from the vent from which the materials originated. They are found on the strongly rolling to rolling slopes on both sides of the Minetué valley at a distance of about 25 miles inland from Pucón. They occur under a rainfall of about 4000 mm per annum, and were once forested: much of the original forest has now been cleared from these soils.

A typical profile shows:-

15 cm dark reddish brown coarse sandy loam, friable but rather weakly structured;
15 cm very dark grayish brown gravelly sandy loam with many small lumps of pumice, very friable and poorly structured;
30 cm yellowish brown fairly tightly packed fine pumice gravel;
50 cm strong brown rather compact loamy sand, weakly structured and with occasional very fine pumice fragments,
On.. various pumiceous strata and thin layers of compact sandy clay loam.

Pucón soils are not well farmed but this is probably due more to the financial and social situation of the many small farmers than to any shortcomings of the soil. Base status analyses (table 4b) show that the soils are of medium base saturation (50% in the topsoil), have a low cation exchange capacity, and are neutral to slightly alkaline in reaction. Probably nitrogen and phosphatic fertilizers would give very good results on these soils. The present manner of soil use is mainly natural pasturage with occasional cropping in oats and sometimes wheat.

viii) <u>Osorno very fine sandy loam</u> (Appendix profile No. 37)

Soils of the Osorno association are developed on landforms of typically undulating to very gently rolling relief, originally mainly under roble forests, and in a rather dry climate for the zone, with between 1250-1500 mm annual rainfall. Their parent materials are somewhat mixed, mainly volcanic ash (mixed rhyolitic and andesitic in origin) re-deposited by wind, but in part the subsoil materials are clearly of local alluvial origin, - perhaps formed by sheet wash of materials over a frozen sub-surface material. The substratum of Osorno soils also varies from gravelly alluvial terrace deposits to peri-glacial deposits having some features in common with glacial till.

A typical soil profile in a moist condition shows:-

20 cm dark brown sandy loam or very fine sandy loam, friable and well-structured but neither sticky nor plastic when moist;
15 cm dark brown very friable silt loam with a tendency to crumble away in exposed road banks;
15 cm dark brown slightly firm silt loam, friable but well-structured and becoming slightly sticky and plastic when moist;
20 cm dark yellowish brown friable heavy silt loam, well-structured and becoming moderately plastic when moist;
20 cm dark yellowish brown grading to strong brown, slightly firm silty clay loam, well-structured and the peds somewhat resistant to pressure at first, distinctly sticky and plastic when moist;
20 cm strong brown firm heavy silt loam with rather weak structure,
On... rather compact gravelly sandy clay.

There are many variations on this profile in the Osorno soil association, but the above example shows most of the significant features of these soils. The substratum is also very variable. Locally, where the substratum is concave in relief, there are patches of slightly to strongly mottled gleyed soils developed.

Osorno soils are slightly acid to near-neutral in reaction, have low to medium base saturation (see table 4b) and probably have only medium base exchange capacities. This may be estimated from the fact that most farmers on these soils report rather good responses to added phosphatic fertilizers, even when used in quite small doses; this would not be likely to occur if the soils had very high exchange capacities.

There are many good farms on these soils, including many dairy farms. Pastures are often managed on a long rotation system, with wheat, oats, and many other arable crops grown in the break between intervals under pasture. Use of nitrogenous and phosphatic fertilizers is fairly heavy on these soils, and crop yields are usually good. Osorno soils are amongst the best managed of all the trumao soils in Chile, and most farms are of a satisfactory size, being neither too large to manage properly nor too small for economic operation.

ix) Pelchuquín fine sandy loam (Appendix, profile No. 38)

Pelchuquín soils are in many respects similar to Osorno soils, being developed on gently rolling to very slightly undulating terrace landforms, from mixed volcanic ash materials emplaced partly by alluvial action and partly as windblown loess. They occur under a rather wetter climate (about 2500 mm rainfall per annum) and were originally under roble forest with a higher proportion of evergreen broadleaf associate species.

A typical profile shows (in the moist condition);-

20 cm brown fine sandy loam, friable and well-structured, and slightly sticky and plastic when moist;
20 cm dark red sandy loam, very friable and difficult to wet if dry (this layer is not everywhere present, but it is nevertheless sufficiently common to be considered a typical feature of these soils: it is produced by the baking of the upper subsoil material during the burning of the forest residues, - especially logs, stumps and large roots);
60 cm dark yellowish brown heavy silt loam to silty clay loam, slightly firm, well-structured, sticky and moderately-to-strongly plastic;
100 cm brown silty clay, very firm and very well-structured, moderately sticky and strongly plastic,
On.. pale brown cemented siliceous tuff, resting on compact gravelly alluvial materials.

No chemical data are available for these soils, but in many respects they are likely to resemble Osorno soils (i.e. to be of moderate base status, slightly acid to near-neutral, and with low to medium cation exchange capacities). The lower subsoil horizons, with their sharply increased plasticity, are likely to have a fairly high proportion of clays other than allophane, - possibly halloysitic and kaolinitic clays.

On the whole these are very well farmed soils, under a programme which permits long rotation pastures, usually built up to a good level of productivity by means of using fertilizers and maintaining a good proportion of clover in the swards. Wheat and oats are said to yield well and fertilizer response to be very good. Some very good dairy pastures were seen on these soils.

5. Soil genesis

Comparing the trumao soils of zone 3 and 4, and with practically no corrôborative evidence yet available from detailed laboratory studies, it is at first sight difficult to justify the claim that the weathering processes are operating with slightly stronger intensity in trumao soils of zone 4 than those of zone 3. It is nearly as difficult to justify the statement that, on the whole, they are subject to stronger leaching intensity as well. The only morphological feature beyong dispute is that the topsoils are more intensively melanised in zone 4 and could undisputably be referred to as 'very strongly melanised'.

The situation is confused by the fact that there have been more frequent and more recent additions of fresh volcanic ash to the soil surface in the case of nearly all the trumao (and ñadi) soils of zone 4. Regarding accumulation of parent materials as a soil forming process, these soils can be characterised as 'moderately accumulating soils' as against the slightly accumulating soils of the trumao areas in zone 3. The addition of this fresh ash to the soil surface is responsible for the superficial 'sandyness' of many of the profiles; for the slightly acid or near neutral reaction of so many of the soils; and analytical data will probably show that most soils show a build up in topsoil fertility. Simple microscopic observations confirm that the fresh minerals added to the soil surface appear to be weathering very rapidly. For example, the thin deposition of fine ash consisting of light-coloured volcanic glass with abundant plagioclase crystals that was spread over the landscape near Lake Ranco by the eruption of Carran peak of the Nilahue volcanic centre in late July, 1955, (analysed by León and Polle, 1956) were re-examined after a lapse of six years. It proved exceedingly difficult to recognise this formerly light gray fine sand layer in the soil itself, but samples were collected from old tree stumps, rock outcrops and from the protected niches in the branch-forks of the larger trees, following the technique used by Oliver (1931) when he proved that Taranaki volcano in New Zealand had been in eruption since the start of Maori occupation of that area. The collected samples of Carran ash were of a dark gray colour when moist, very humic and sandy loam in textures. Under the microscope they appear to consist almost entirely of porous volcanic glass in a quite highly weathered state, and no felspar crystals of any kind could be found. The former cation exchange of this material immediately after the eruption was about 3.8 m.e.%; the present capacity is over 60%, although in part this will be due to the high organic matter content. The material still contains a high proportion of exchangeable cations (principally calcium and magnesium) but the base saturation has decreased from 100% to about 65%. Citric soluble ('available') phosphate which was formerly over 6 ppm has now decreased to less than 0.01 ppm. On this rather slight evidence, it would appear that weathering has indeed been intense in the zone and that in a period of six years there has been complete destruction of the plagioclase felspars, and considerable attack of the volcanic glasses, to produce what is almost certain to be amorphous colloidal alumina and silica compounds, and organo-mineral complexes.

There are some, perhaps significant, differences in profile morphology between trumao soils of zone 3 and 4. It is not surprising that the subsoil shrinkage fissures are absent or only exceedingly weakly developed in zone 4 trumaos; nor is the thin very friable horizon immediately below the topsoil conspicuously developed. There is the normal range from friability to firmness in the different horizons and strata, but one gets the additional distinct impression that the soil materials are more compactly knit together (without being at all compact) in zone 4 trumaos. This feature may be connected with a new property appearing in connection with individual soil aggregates: in many soils the structural peds are very well formed (no matter what size or shape) and for a brief moment they seem to resist pressure to a far greater degree than peds from the trumaos of zone 3. This feature would probably have escaped notice if it were not for the fact that it becomes still more pronounced in the trumaos of zone 5, where it can be seen at times in its ultimate expression, as a thin coating of iron oxide around individual peds. Investigation of this incipient feature of zone 4 trumaos lies in the field of the micromorphologists, and samples have been sent to A. Mella, at present in Hamburg to see if this feature can be more precisely characterised by examination of thin soil sections.

Clayskins, clay flows and even pressure faces are remarkably rare in the trumao soils of zone 4. This observation, added to the observations mentioned above, leads to the possible conclusion that the allophane clay in these soils is normally in a higher state of hydration, less mobile; and that the structural cracks in the soil material are becoming more permanent and perhaps defined by the development of a very fine silica or iron coating around the structural peds. Drying out of the soil may be mainly confined to these structural cracks and not to the whole soil mass.

A feature not brought out clearly in the detailed soil profile descriptions of the Appendix is that, in the trumao soils of zone 4, there is almost invariably a distinct change in soil colour when the aggregates are crushed to their ultimate size. A subsoil aggregate that has a surface colour of 5YR 3/4 or 7.5YR 3/2 (i.e. dark reddish brown or dark brown) will commonly crush to a colour of dark yellow brown (10YR 4/4). This suggests that the peds may be coated more with humus colloids than any other substance, and this agrees with the fact that weathering lumps of pumice that occur in many of the subsoil strata appear to be quite rich in humus. When heated such lumps usually change from yellowish brown or brownish yellow to almost white. There is little doubt that considerable amounts of humus are moving through these soils, and in the absence of the necessary chemical data, one may pre-suppose that soil leaching is quite strong and probably intensified by the organic acids derived from the humic surface horizon.

6. Soil classification

In Chile these soils are regarded as Trumao soils, so far not specifically differentiated from the central or northern trumao soils. They are however regarded as a different entity by most farmers.

In the classification outlined in the 7th Approximation of the U.S. Department of Agriculture, they are probably Mollic Umbrandepts.

In the earlier classification of New Zealand they are Yellow Brown Loams and Yellow Brown Pumice Loams of various degrees of weathering and leaching, but predominantly moderately-to-strongly weathered and moderately -to-strongly leached, and strongly melanised. In the recent system of Pohlen (ibid, 1962), they are probably "strongly enleached alvic loams from mainly moderately-to-strongly argillised andesitic and fine rhyolitic ash with inclusions of moderately enleached subalvic loamy sands from weakly argillised coarse rhyolitic pumiceous ash".

Apart from the rather high pH status of some topsoils, these trumao soils come closest to the Humic Allophane group characteristics set down by Kanno (ibid, 1962) for the Japanese Volcanic Ash soils.

Provisionally, it is sufficient to recognise them as allophanic soils derived from volcanic ash materials in a zone of fairly strong weathering with no distinct summer dry season, under strong leaching processes but with intermittent surface accumulation of fresh volcanic ash, and showing strong melanisation. In short: strongly melanised, moderately-to-strongly weathering and leaching, moderately accumulating allophanic volcanic ash soils of a cool humid environment derived from highly siliceous and moderately siliceous materials.

f) Trumao soils of environmental zone 5

In this zone trumao soils again appear fairly widely dispersed over the South Chilean landscape, extending in places from the Argentinian border in the east, to the Pacific shore in the west. The ash mantle is not as complete as in zone 3 or 4, but considerable patches of ash-derived soils occur on most land-forms, including the very steep slopes of the Andean ranges. Ñadi soils are also developed on some of the poorly drained terrace landscapes but they are not as extensive as in zone 4.

Most of the trumao soils of zone 4 are derived from materials deposited directly on the landscape as subaerial volcanic ash in the case of the mainland area, but on the island of Chiloé, a number of the soils appear to include subsoils materials, that may be of loessic or alluvial origin. The precise origin of the soil material of the trumaos on Chiloé Island is still rather confused and will be discussed at greater length when considering the origin of the ñadi soils.

The volcanic ash mantle lies especially thickly on the slopes Andean cordillera in the vicinity of the volcanoes, of which there are about eight occurring within the zone. The volcanic ash soils of the steep slopes of the Andes will be referred to again in the section on 'steepland soils derived from volcanic ash'.

Soil parent materials very fairly widely, but are characteristically somewhat pumiceous; more so than in zone 4 and very much more so than in zone 3. Many of the fine ash beds that appear to be chiefly andesitic in nature usually contain quite large grains of porous siliceous sand approximating to fine pumice. Distinct pumice layers are fairly common in Aisén Province.

Unfortunately there is no mineralogical data available for the trumao soils of zone 5: nor yet are any base status analyses available.

1. Environmental characteristics of the zone

The climatic regime of this zone includes a range of mean annual precipitation, from about 2000 mm in the west, rising to over 5000 mm in the central Andean ranges, and then declining to about 1500 mm over the eastern side of the Andes. No month in the year regularly receives less than 60 mm and the soils are more or less continuously moist under natural conditions. Between 15 and 20% of the rain falls in the summer; about 30% on the winter, and the remainder spread fairly equally between the spring and autumn months. In some years the spring is distinctly drier than the summer. Over the eastern Andes, a good deal of the winter precipitation falls as snow, which may last on the ground for several weeks.

Mean annual temperatures lie between 8°C and 10°C, with mean winter (July) temperatures ranging from 4°C and 8°C, and mean summer temperatures (January) between 18°C and 20°C.

Over the western part of the zone the nearest climatic analogue is probably Westport in the Westland Province of New Zealand; while that of the Andean fiords is probably not unlike the Fiordland climate of New Zealand (Wright, 1952).

In this zone, the deciduous roble (Nothofagus obliqua) virtually disappears but another deciduous Nothofagus (lenga: N. pumilio) appears on the eastern Andean ranges. Nothofagus antarctica (ñirre) also becomes common in the eastern limit of the zone, but the dominant trees, ranging over almost the whole width of the zone are coigüe (Nothofagus dombeyi), Weinmannia trichosperma, and Laurelia serrata. Canelo (Drimys winteri), tepu (Tepualia stipularis), mañío (Podocarpus nubigensis), alerce (Fitzroya patagonica) and Saxegothea conspicua are of more local occurrence. Quila and coligüe (Chusquea spp.) are fairly widespread.

Associated non-trumao soils in this zone include Gley Podzols, Podzols, Podzolised Gley soils, Alpine meadow soils, Organic or Bog soils, Acid Brown Forest soils and Humic Gley soils; many of these being developed on rather steep slopes, and hence somewhat lithosolic in form.

2. General soil morphology

Topsoils:
- generally between 15 and 25 cm in depth and often distinctly peaty, with a layer of forest litter or forest peat (mor) in places where the natural forest is undisturbed;
- colours generally black, very dusky red or very dark brown when moist; dry colours are seldom seen in nature but soil dried for laboratory purposes usually shows very dark grayish brown to dark grayish brown colours; very deep and dark Andosol-type topsoils are comparatively rare;
- topsoil textures are predominantly silt loam, although fine

sandy loams are also quite common, especially in Aisén Province;
- structural development is everywhere good and very well-defined;
- many topsoils have very water-stable aggregates and float on water in their dried condition; aggregates are often slightly to strongly resistent to pressure and have a decided 'crispness' when moist;
- topsoils are almost invariable friable when moist and quite soft when dry; they are also usually slightly plastic and sticky;
- the lower limit of the topsoil is usually quite distinct, or slightly diffuse, but never abrupt.

Subsoils:
- subsoil colours are always rather dark, ranging from very dark brown or dark reddish brown to dark yellowish brown in the moist condition; dry subsoil colours are only found in nature on exposed soils of road banks or ditch walls, and are usually brown or rather dark yellowish brown;
- subsoils are usually conspicuously stratified at some point but buried topsoils are very rare; the total degree of profile stratification is less than in zone 4;
- textures of subsoil materials are generally rather heavy, ranging from loam to clay loam or even silty clay; there are usually no loose or powdery (dry) horizons in the profiles, but the soils are generally easier to dig than many soils of zone 4, - possibly due to the unusually deep friability of these soils of zone 5; firm or very firm subsoil;
- horizons are seldom encountered within the first metre of depth; most subsoil materials are quite sticky and often moderately (or even strongly) plastic in nature;
- structural aggregation is well developed, but the aggregates are usually rather finer than in zone 4; an additional feature is the marked firmness of these peds when not excessively moist, and the presence of thin iron-oxide coatings around many of the peds in the lower subsoil horizons;
- distinct bleaching and graying of the upper subsoil materials occurs in some soils, indicating the incipient formation of a very strongly leached (or weakly podzolised) horizon;
- without exception, subsoil materials are markedly 'greasy' and 'slippery' when squeezed in the hand;
- subsoil horizon boundaries are usually diffuse if they are due to acquired characteristics, and often abrupt if they are due to inherited characteristics, with the exception of the formation of thin iron-pan horizons which always have very sharp upper and lower limits.

3. General chemical characteristics

At the time of writing, chemical data are completely absent for the trumao soils of this zone. Neither base status, mineralogical information of the sand fractions, nor clay determinations are yet to hand.

4. Characteristics of typical soils

Six of the more typical trumao soils of this zone have been described in detail in the Appendix. All these soils are derived mainly from subaerial volcanic ash of andesitic or rhyolitic nature, but some of the soils contain strata that have some of the characteristics of volcanic loess in which the andesitic and rhyolitic features are intermingled. It is very common, in this zone, to find pale brownish to yellowish-white specks of very finely porous siliceous material extending through one or more of the subsoil layers. Four of the soils described in detail are from Chiloé Island; two are from the Province of Aisén.

i) Castro silt loam (Appendix, profile No. 39)

Castro soils are developed in the eastern central part of Chiloé Island on rather strongly rolling landscapes but with some sectors gently rolling to undulating. They are distinctly stratified soils (see also Wright, 1958, p. 118) and in most cases the ash beds and shower layers smoothly follow the present topography in a way that suggests that volcanic materials of loessic or alluvial origin have played little part in their formation. The soils are developed under mixed Valdivian coastal forest of the variant called 'Chiloé Forest' by Pisano (ibid, 1950), in which the more important trees are Eucryphia cordifolia, Weinmannia trichosperma, and Laurelia serrata (E.J. Godley, pers. comm., 1959; and Godley, 1960), with local abundance of Nothofagus dombeyi. Mean annual rainfall is slightly over 2000 mm of which 11% falls in the summer and 43% in the winter.

The soil profile shows:-

20 cm very dark brown silt loam, friable, granular and slightly sticky and plastic. (field pH, 5.0);
34 cm similar material but slightly less dark brown and with a medium subangular blocky structure. (pH, 5.0);
36 cm very dark yellowish brown slightly firm loam with well developed blocky and granular structures. (pH 5.0);
10 cm similar matrix as above but with irregular lumps of an old mud shower, of paler yellow brown colour, of rather stronger firmness and which become quite hard when dry. (pH of lumps, 5.3);
40 cm dark yellowish brown slightly firm sandy clay loam with a poorly developed structure in the mass. (pH 5.3);
70 cm dark yellowish brown grading to yellowish brown friable sandy clay

loam grading to sandy loam of generally weak structure. (pH, 5.3),
On.. dark brown somewhat compact gravelly coarse sandy loam.

Castro soils are probably of rather low base status and probably have a high cation exchange capacity (up to 50 m.e.%). Many local farmers regularly apply seaweed or farmyard manure to these soils, and those that can afford it also apply phosphate and nitrogen. The soils are used mainly for potato, and oat crops, with intervals of volunteer pasture invasion between cropping years. The rotation interval is rather short (3 to 4 years) mainly owing to the economic circumstances of the majority of the farmers.

ii) Quellón silt loam (Appendix, profile No. 40)

Quellón soils are developed in southeastern Chiloé island on landscapes of rolling to strongly rolling relief carved mainly out of periglacial deposits. The ash mantle is about 1.5 to 2 m in thickness, and contains a large amount of very fine porous siliceous sand. The natural vegetation still occupies most of this soil, and consists of forest dominated by Nothofagus dombeyi, equivalent to the 'North-Patagonia Rainforest' of Schmithüsen (1956). The mean annual rainfall is in the vicinity of 3000 mm, of which about 16% falls in the summer and 43% in the winter months.

The soil profile shows:-

20 cm black friable and granular silt loam that is slightly sticky and plastic when moist. (field pH, 4.8);
30 cm very dark brown slightly firm silt loam with good medium blocky aggregation and rather firm peds. (pH 5.0);
100 cm very dark brown, rather firmer silt loam with much weaker aggregation, but peds still show crispness when separated. (pH 5.6);
15 cm yellowish brown heavy silt loam. (pH 5.9),
On.. compact and cemented glacial materials.

Quellón soils appear to be of low natural fertility and a considerable amount of land that has been cleared for farming has subsequently been abandoned. Only near the coast, where land can be readily dressed with rotting seaweed and animal manures, has farming persisted with any success. Attempts to manage this soil under permanent volunteer pastures without fertilizing artificially has unquestionably failed, and the amount of grazing produced under these conditions is so low that few farmers bother to repell the invasion of forest seedlings, rushes and introduced weeds such as blackberry which inevitably occurs on poorly managed pastures. Probably the cation exchange cpacity and phosphate fixing capacity of this soil is so high that a very heavy capital outlay would be needed to establish farms of adequate productivity to pay the high costs of maintaining the fertility on these soils. In view of the present difficulties of communications and shipping farm produce to mainland manufacturing centres, it is doubtful if such a capital investment can be justified. The majority of the farmers are little more than subsistence farmers, with their main source of income coming from timber extraction and fishing.

iii) Mañiuales silt loam (Appendix, profile No. 41)

Mañiuales soils are developed mainly in Aisén Province and in parts of continental Chiloé Province under a mean annual rainfall of about 3500 mm, of which almost 20% falls during the summer and 30% in the winter months. It is a soil of old terrace remnants and hillside ledges of the main trans-cordillera valleys, such as the Simpson valley; of small total extent but with an ash mantle often more than 3 m deep. Most of this material is from direct subaerial accumulation, but in places there has been considerable colluvial thickening of the mantle. In general the relief associated with this soil is strongly rolling. The material is mainly andesitic, but pumiceous layers also occur in the subsoil.

A typical soil profile shows:-

17 cm very dusky red to black slightly firm very strongly structured silt loam, often rather peaty;
14 cm dark reddish brown slightly firm strongly structured fine sandy loam, in which the peds are very crisp;
6 cm yellowish red pumiceous gravelly sandy loam without structure in the mass;
7 cm dark reddish brown friable coarse sand, in part pumiceous but mainly porous siliceous sand grains mixed with many black sand grains;
35 cm reddish brown firm very fine sandy loam grading to silt loam without well-defined structure;
70 cm strong brown grading to yellowish red rather firm, silty clay loam with a very good structure and with crisp, resistent peds,
On.. bouldery terrace gravels.

These soils are often farmed in conjunction with the nearby river bottomland, and are maintained in permanent rough pasture to provide winter feed when the river are in flood. They do not appear to be very fertile, since pastures are generally poor and heavily invaded by shrubs and trees, by rushes and by blackberry. It is anticipated that they will have a rather low base status, high base exchange capacity and high phosphate fixing capacity. No fertilizers are in use at the present time, and it is doubtful if it would be economic to do so.

iv) Puerto Lumas sandy loam (Appendix, profile No.42)

Puerto Lumas soils are found in the vicinity of Aisén town, and further to the west and south. They are characterised by the presence of an uppermost layer of pumiceous volcanic ash which forms the whole of the topsoil horizon and the upper part of the subsoil. In many places the lower part of this pumiceous material is weakly cemented, probably by silica. However, it is not sufficiently cemented to constitute a serious impediment to drainage. The lower subsoil layers are variably andesitic, and/or rhyolitic and pumiceous, but of finer grade and much greater age than the uppermost materials. Puerto Lumas soils are developed on old terrace landforms, on hillside ledges and on floodplain remnants in the Lower Simpson valley, under rainforest dominated by laurel, tepa, coigüe, etc., with abundant quila; and under a mean annual rainfall of about 2800 mm, of which about 20% falls in the summer and 30% in the winter months.

The soil profile shows:-

18 cm	very dark reddish brown friable sandy loam with a good granular structure;
15 cm	yellowish brown, rather firm, coarse sandy loam or sandy clay loam, often weakly cemented in place but will break into regular angular blocks when displaced;
20 cm	brown to yellowish brown very firm and partially cemented coarse sand with an abrupt lower boundary;
2 cm	dark reddish brown layer of coarse sand and fine pumice that is quite loose when displaced;
17 cm	brown to dark brown firm heavy coarse sandy loam or coarse sandy clay loam, well-structured and moderately plastic;
30 cm	strong brown to dark yellowish brown, somewhat friable fine sandy clay loam, well structured and with very cris peds coated lightly with iron-oxide and faint indications of a very thin iron pan developing in about the centre of this horizon,
On..	dense gravelly clay, often with a distinct but thin iron-pan marking the junction with the horizon above.

Puerto Lumas soils are being fairly successfully farmed in the vicinity of Aisén town, where they are used for dairying with intervals of cropping under market garden vegetables. Their fertility is probably not high, but it is expected that they have a much lower (perhaps 25 m.e.%) cation exchange capacity and a higher base status than Mañiuales soils. Little fertilizing is carried out on these soils, yet the proportion of white clover in the pastures is quite good. They may have some natural phosphate available to plants, and their overall phosphate fixing capacity may be fairly low. They are probably, nevertheless, slightly phosphate deficient (and nitrogen deficient) which would show up strongly if these soils were to be more intensively farmed. Owing to the slight impedence caused by the cemented part of the subsoil, pastures tend to become severely invaded by rushes, and where this has not been controlled some of this soil has gone out of production. Once heavily invaded by rushes the land is much more difficult to plough.

v) Natri peaty fine sandy loam (Appendix, profile No.43)

Natri soils are mainly under their natural Nothofagus dombeyi forest, and only small farm clearings have been made alongside the road leading from Castro towards Quellón, in Chiloé island. They are developed on broadly rolling terraces carved mainly in periglacial alluvial materials consisting of gravels, sands and clays very firmly compacted and in places cemented. For this reason, Natri soils occur complexly associated with Ñadi soils, peaty gley soils and peat bogs; the degree of wetness of the situation being mainly decided by the flatness of the relief. Natri soils are more common towards the edges of the terrace landforms, where the slopes are rolling and drainage is slightly better. The parent materials of the soils are probably mainly subaerial volcanic ash of both andesitic and rhyolitic origin, but some loessic and perhaps alluvial materials are also present in the subsoil layers.

A typical profile shows:-

15 cm dusky red forest peat, very fibrous (mor)
15 cm dark reddish brown, rather compact fine sandy clay loam with many iron-oxide depositions in old root channels, but well-structured and with crisp peds;
13 cm dark reddish brown very firm, almost compact, very strongly structured fine sandy clay loam, the larger prisms and blocks are strongly coated with iron-oxide and the material is moderately plastic;
47 cm reddish brown slightly firm silty clay with a very strongly developed structure but not so coarse as in the last horizon, peds very firm and thickly coated with iron-oxide, to the extent that almost a iron-oxide latticework is formed in the soil;
25 cm dark brown to strong brown faintly mottled sandy clay loam, friable and with a weak structure,
On.. coarse gravels and sands cemented with iron-oxide, manganese, and probably silica; the iron-pan is up to 0.5 cm in thickness in places, and usually forms a continuous sheet.

Natri soils are proving very difficult to farm on account of their undoubted very low fertility. The present farmers are finding it difficult to make a living even while they are farming mainly on the accumulated forest litter fertility; and without very skillful management, abundant capital and heavy regular application of fertilizers (mainly phosphate and nitrogen, but perhaps also lime and potash) these farming ventures will undoubtedly collapsed. Family incomes are at present augmented by sale of timber and by engaging for work on road construction. There is no indication, in the present situation, that farming will prosper on these soils, and the land is far better left in forest to swell the timber resources of the Nation. Deliberate destruction of the forest on these soils to make way for farm developments is a wilful waste of the natural resources of the region.

vi) <u>Chepu very fine sandy loam</u> (Appendix, profile No. 44)

Chepu soils are commonly found in association with Castro soils in the western-central parts of Chiloé Island. They are developed in places where the ash beds are slightly more sandy and where the forest has a high proportion of strong mor-forming (i.e. surface-peat building) species, - particularly Podocarpus sp., Saxegothea sp. and Weinmannia trichosperma. The Chepu soil profile is thus seldom continuous over a very wide area, occurring mainly in patches corresponding to the composition of the forest canopy, and the intervening soils have profiles more reminiscent of Castro soils. The Chepu profile thus arises mainly as a result of the conditioning power of the vegetation. These soils were first described by Wright and Funes (see Wright, 1958) and are very similar in origin to some soils of the South Island, New Zealand (Wright, 1951; 1959).

Chepu soils are developed on rolling to undulating relief; under mixed evergreen forest dominated by Laurelia, Eucryphia, with local abundance of Weinmannia, Aextoxicum, and occasional stands of Podocarpus and Saxegothea; and under a rainfall of about 2750 mm per annum with up to 25% falling in the summer months.

The soil profile shows:-

5	cm	dusky red fibrous loamy peat;
20	cm	black, distinctly peaty, fine sandy loam, friable and with very strong and coarse structures;
10	cm	pinkish gray slightly firm, well-structured very fine sandy loam;
0.3	cm	very thin discontinuous iron-humus pan that forms a distinct coating around the peds;
35	cm	strong brown grading to dark yellowish brown heavy silt loam grading to light silty clay loam, friable and rather weakly structured;
20	cm	yellowish brown slightly firm silty clay loam with weak structures but moderate plasticity,
On..		reddish yellow partially cemented loamy sand, resting on gravels embedded in heavy clay.

Chepu soils thus show distinct signs of very strong leaching which has progressed to the stage where the profile shows signs of podzolisation. No chemical data are yet available for these soils, but it may be anticipated that they will be of low base status, and somewhat deficient in most plant nutrients. They are likely to have moderate to high cation exchange capacities, and a fairly high rate of phosphate fixation. In their morphology, they somewhat resemble the Te-Rau-Moa silt loam of New Zealand; and the latter soils are known to respond to phosphate, lime, nitrogen and several minor elements. Taylor (1933), for example, reports the appearance of definite podzol characteristics in some soils derived from andesitic volcanic ash in New Zealand.

Farming on Chepu soils is clearly more difficult than on Castro soils; crop yields are low once the stored fertility of the natural forest topsoil is exhausted, and most of the Chepu soils are either occupied by run-out pastureland, or are abandoned to invading forest species, or are still under their original forest. Much of the farm income comes from exploitation of the timber trees and fence-post splitting from smaller trees, in the patches of forest still remaining on the land. Chepu soils could be brought into a fairly high level of agricultural production, but the cost is likely to be far beyond the financial means of the present farmers.

5. Soil genesis

Although chemical and physical data for the trumao soils of zone 5 is completely lacking at present, there is little doubt about the genesis of these soils: practically all the trumao soils of this zone show very clearly the effects of strong leaching processes.

The intensity of the weathering processes are expected to be little different from that in the soils of zone 4, - i.e. 'moderate-to-strong', but it would appear that addition of fresh volcanic ash to the soil surface has been much less frequent in zone 5 than in zone 4, and so the majority of the surface soil material is rather older than that of the zone 4 trumaos. Zone 5 trumaos are very weakly accumulating soils, and certainly there has been no important addition of volcanic ash in recent years.

Zone 5 trumaos are all very strongly melanised, but the nature of the melanisation is perhaps rather different, being composed of humic compounds of a very dark reddish colour. In most soils under natural conditions, the forest residues accumulate slowly and build up a layer of acid 'mor', or forest peat, on the soil surface; and from this layer the percolating rainwater picks up strong organic acids and other complex humic compounds which find their way down the soil profile.

Subsoils are normally very moist in their natural state and there is probably a sharp contrast in chemical and physical conditions between the soil material adjacent to the structural channels and that of the interior of the soil aggregates. The appearance of the subsoils in drying road banks shows that the subsoil material has considerable capacity for shrinkage. It is possible that the soil aggregates are composed of much more hydrated allophane clay towards their centre; and around their periphery, in the vicinity of the structural fissures, reactions with percolating organic compounds produces a more floculated type of clay, giving the particular sensation of crispness to the peds which is characteristic of all these soils. In cases where deposition of iron-oxide occurs in the subsoil, this appears first as a very thin veneer around the peds; in some cases thickening until almost a latticework of very thin iron-pan forms throughout a particular subsoil horizon; but in other cases the iron accumulation has a more pronounced linear arrangement and gives rise to a more normal iron-pan.

Bleached 'A_2' horizons and gleyed or mottled 'B' horizons are by no means common, but they do appear as incipient features in the more siliceous of these trumao soils. They are far more common in the associated ñadi soils of this zone.

Distinct clayskins or clay flows have never been recorded in the trumao soils of this zone; nor does distinct clay illuviation occur. The increasing heaviness of texture with increasing depth that occurs in many profiles is due to the greater age of the lower subsoil layers, and is probably due to the gradual change of amorphous allophane to crypto-crystalline and crystalline forms of clay. In some subsoils, waxy gibbsitic-looking nodules have been recovered from these subsoil layers showing heavier textures and moderate or strong plasticity. Analyses of these (Birrell, pers. comm. 1962) show that they are almost 100% gibbsite.

6. Soil classification

The trumao soils of zone 5 have not been greatly studied in Chile. They are recognised, in a general way, as being soils closely related to the more typical Trumaos of the rest of Chile, and are often spoken of as Trumao-Ñadi intergrading soils. In Western Chiloé, Roberts and Díaz (ibid, 1959) include them with the Podzol-Alpine Meadow group. Roberts (Roberts, et. al., 1958) mentions their relationship to the Brown Latosols and Reddish Brown Lateritic soils.

In the 7th Approximation (ibid, 1960) these soil appear to lie between the Mollic Umbrandepts and the Mollic Durandepts, but their true position is rather obscure.

In the earlier classifications of New Zealand, they would mainly be regarded as strongly leached Yellow Brown Loams (New Zealand Soil Bureau, 1954). In the classification of Pohlen (ibid, 1962) they would probably be regarded as mainly "very strongly enleached alvic and podi-alvic soils".

It is doubtful whether the majority of these soils fall within the limits set by Kanno (ibid, 1962) for the Humic Allophane soils of Japan; they are acid enough but lack many of the morphological features that he describes for the soils of this group.

Provisionally it is sufficient to recognise them as allophanic soils derived from volcanic ash materials in a zone of fairly strong weathering with no distinct summer dry season, developed under very strong leaching intensity (in part conditioned by the mor-forming plant cover), and showing very strong melanisation. Or, put another way: 'very strongly melanised, very strongly leached, moderate-to-strongly weathered allophanic volcanic ash soils of cool, humid environments, derived from moderately to highly siliceous materials'.

g) Trumao soils of environmental zone 6

The trumao soils of zone 6 comprise very strongly weathered soils derived from volcanic ash, and, in Chile, these soils are only found in a very small area on Easter Island.

1. Environmental characteristics of the zone

Easter Island consists mainly of andesitic lavas, scoria and tuff beds (Chubb, 1933). There are three distinct main volcanic vents, and these form the cones at the three apices of the triangular island. The softer tuffaceous rocks of these three old cones have been cliffed by the sea to form high, blunt promontories, and the trade winds stricking against these cliffs carries upwards a large quantity of eroded volcanic minerals, some of which is later deposited on the landscape of the island. In addition to this source of finely divided volcanic material, there is a considerable amount of much older volcanic ash mixed with the scoria of the volcanic cones. Since this finely divided material weathers very rapidly in this environment, it is often very difficult to distinguish clearly the soil components derived from volcanic loess and volcanic ash; and to distinguish either from the normal weathering products of the more substantial tuff beds and lavas.

Nevertheless, it is considered (Wright and Díaz, 1963, in press) that allophanic volcanic ash soils derived from volcanic ash are present on the island and can be recognised as such. The soils named Rano Kao, Vinapu and Poike (and perhaps Kanina) are of this type.

The climatic regime of Easter Island is practically tropical. Knoche (1913) designates it as 'tropical'; Skottsberg (1920) calls it an 'oceanic warm temperate climate dominated by trade winds' and Heyerdahl (1961) sums it up as a fairly equable semi-tropical climate. It is certainly a very warm, moderately humid climate, not unlike that of Raoul Island in the Kermadec archipelago (Wright and Metson, 1959). Mean annual rainfall is about 1200 mm, rather evenly distributed through the year. Air temperatures are of the order of 20°C, with a narrow range between mean maximum air temperatures (24°C) and mean minimum temperatures (17°C). Evaporation rates are, however, very high, and more than half the total rainfall is evaporated soon after it has been received. Mean soil temperatures are, on the whole, rather high, (23°C). From time to time severe drought conditions have been recorded, lasting several months.

The natural plant cover of the island was probably never more than grassland with patches occupied by low trees of Sophora toromiro. Skottsberg (ibid, p. 492) suggests that the poverty of the plant cover was due to the extreme isolation of the island, and that the original vegetation probably consisted of a park-like savanna with occasional groves of trees and shrubs in sheltered depressions and on the low slopes of the hills. The present vegetation is mainly Sporobolus grassland, and the island has rather dreary, barren aspect.

Associated non-trumao soils on the island are rather difficult to classify. They appear to be somewhat similar to some of the younger latosolic soils of Western Samoa (Wright, ibid, 1963).

2. General soil morphology

Topsoils:
- colours are mainly brown to reddish brown, becoming more strongly red when there is admixture with scoria;
- textures are commonly fine sandy loam, with heavier textures appearing when there is admixture with scoria;
- topsoil depth is usually less than 25 cm;
- consistence and structure vary rather widely, but the topsoils are usually somewhat friable, usually quite well-structured and slightly sticky and plastic when moist;
- the lower topsoil boundary is often not very distinct.

Subsoils:
- colours are mainly reddish-brown to red;
- textures are fairly heavy, ranging from clay loam to clay;
- the subsoils are not distinctly stratified as a rule, but two or three distinct soil boundaries can usually be seen;
- the upper part of the subsoil may be friable but firmness appears with increasing depth; stickyness and plasticity also increase with depth.

3. General chemical characteristics

A large amount of the essential data concerning the chemical characteristics of the trumao soils of zone 6 is still lacking. That which is available is shown in tables 8a, 8b and 8c.

The fusion analyses refer to the whole soil and not only to the clay fraction, and therefore they are not comparable with the data presented in tables 1 to 4. They do however show that the silica/alumina ratios are low. Cation exchange capacities are medium to high, and the easily extractable phosphate is very low indeed, suggesting that a considerable amount of allophane may be present in these soils.

The total and exchangeable calcium and magnesium is very low, and the percentage base saturation is likely to be very low; field pH figures for Poike silty clay loam subsoils are usually less than 5.0 (i.e. moderately to strongly acid) and few field pH tests showed any of the soils to be better than moderately acid. Organic matter content is medium to low; probably very low in many of the soils. Of the minor elements present, there is an almost complete lack of barium and strontium, while molybdenum, chromium, and possibly also zinc and boron (Wells, pers. comm., 1962) are likely to be low in these soils.

The chemical data so far available thus indicates soils that are very strongly leached, and clay fractions that probably have a significant amount of allophane in their composition.

4. Characteristics of typical soils

Three of these allophanic volcanic ash soils are described in full in the Appendix. They represent soils from scoriaceous materials with varying amounts of more recent fine ash material deposited on the soil surface. The Rano Kao profile has about 25 cm of this younger, probably loessic, dust in the upper part of the profile; the Vinapu soil has nearly 70 cm of material of similar origin over the weathering scoria; while the Poike soil described has little distinguishable recent dust but probably incorporates considerable amount of volcanic ash material amongst the soil which is in part derived from andesitic tuff.

i) Rano Kao heavy fine sandy loam (Appendix, profile No. 45)

Rano Kao soils are developed on the western planeze slopes of Rano Kao volcano at altitudes ranging from about 20 m to over 300 m. They have a general slope of between 6° and 14°, and were probably originally developed under a light scrub forested of Sophora and under grassland.

The soil profile shows:-

25 cm brown to reddish brown (moist) heavy fine sandy loam, slightly firm and quite well-structured. (pH 5.9);
40 cm reddish brown (moist) very friable clay loam, not well structured in the mass, but breaking readily to very fine granules and crumbs. (pH 5.8);
90 cm red (moist) firm silty clay with a weak structure but strong plasticity. (pH 5.8);
On.. red silty clay with lumps of weathering scoria.

Rano Kao soils have been used for growing maize with some success but the intervals between crops would probably have to be rather long if not fertilizers are used. Field trials (Schanz, pers. comm., 1962) suggest that these soils are very responsive to phosphate, and may also be responsive to small dressings of molybdenum in the case of leguminous crops like alfalfa.

ii) Vinapu very fine sandy loam (Appendix, profile No. 46)

Vinapu soils are found on the lower northeastern slopes of Rano Kao volcano, and are deep friable soils long used for maize cropping by the islanders. They appear to be formed mainly by the accumulation of loessic materials blown by the trade winds form the adjacent cliffs. They occur at altitudes ranging from about 20 m to about 200 m, and were probably originally covered with natural grassland. Their relief is gently sloping to strongly sloping, with an average slope of about 7°.

The soil profile shows:-

28 cm dark brown to brown (moist) friable very fine sandy loam with no recognisable structure in the mass. (pH 5.4);
40 cm dark brown to dark reddish brown (moist) very friable sandy clay loam with no recognisble structure in the mass but crumbling very readily to granules and crumbs, and containing some carbon fragments at about the 50 cm level (pH 5.6);
70 cm reddish brown (moist) friable clay loam, also rather structureless in the mass but breaking to granules. (pH 5.7),
On.. reddish brown (moist) firm silty clay with strongly developed structures. (pH 5.8).

Vinapu soils have been rather heavily cropped with maize in the past and are now showing distinct signs of impoverishment. Small scale fertilizer trials with N-P-K treatments have shown that these soils respond well to all three fertilizers singly and in combination and, in addition, some response was shown by clovers to molybdenum in very small quantities.

iii) Poike silty clay loam

Poike soils are developed on the broad planeze slopes of Mt. Poike at the eastern apex of Easter Island, above the sheer cliffs of Poike peninsula. The general landscape is undulating to rolling, with a general slope towards the cliff top of about 8° to 14°. The altitudinal range of these soils is from about 60 m to 200 m. The soils are almost certainly formed mainly from volcanic loess blown from the cliff face, but the junction between this material and the older soils derived from andesitic tuff and older subaerial ash deposits is very difficult to detect in the soil profile. The original plant cover of Poike soils was possibly Sophora woodland, but more likely was natural grassland.

The soil profile shows:-

30 cm dark brown (moist) rather firm silty clay loam with a well-developed structure. (pH 5.1);
35 cm brown (moist) friable silty clay, of rather weak structure. pH, 5.0);
50 cm reddish brown (moist) silty clay, slightly compact in place but friable when displaced and with a well-developed structure (pH, 4.9);
35 cm yellowish red (moist) rather firm silty clay with poorly developed structure. (pH 4.8),
yellowish red silty clay with weathering tuff fragments.

Poike soils are used only for grazing purposes and there is little to indicate what their fertility status might be. No chemical data are yet available and one small field trial with fertilizers was affected by a severe drought soon after it was laid down. The indications are that these soils are of rather low base status, and particularly low in phosphate. It is expected that further analyses will show that Poike soils have considerable allophane in their clay content, have a high cation exchange capacity, low total exchangeable bases and base saturation, and high phosphate fixing capacity.

5. Soil genesis

The genesis of the great stone monoliths on Easter Island is not nearly as mysterious as the genesis of the soils of the island.

It is difficult to explain the general condition of the soil on the basis of the current environment of the island: the soils are far more leached and rather less weathered than one would expect from comparison with soils from similar parent materials developing under the same kind of environmental conditions in other parts of the world.

This comment is valid for all the island soils (see also Wright and Díaz, 1963, in press), but is particularly true for those soils that are regarded as being allophanic in nature. There have certainly been no recent volcanic eruptions on the island, and probably none during many thousands of years. The landforms are quite old and therefore the majority of the soils should be very strongly weathered.

The subsoil materials are indeed strongly weathered, but many topsoils show textures that are but little heavier than loams. In part this is probably due to the steady accumulation of loess-size dust derived from the abrasive action of the trade winds against the long and steep cliff slopes, but in part may be due to the almost irreversible drying out of part of the clay fraction during the short but severe drought periods that are experienced on the island. Casual inspection of the soil material under a field microscope shows very little unweathered mineral matter apart from a considerable amount of magnetite and some very minute iron-oxide aggregations. In this, they are reminiscent of the Hakupu loams of Niue Island (Wright, 1963, in press) which are also believed to be mainly of volcanic ash origin with some admixture of deep-sea sedimentary material: the apparent 'loamyness' of the topsoil may not be indicative of the stage of weathering.

The base exchange capacities of these soils are medium to high. This taken in conjunction with the evidence of very low phosphate availability, the high cation capacity does suggest that significant amounts of allophane may be present. The clay fraction is expected to consist of some allophane with perhaps a fairly high proportion of crystalline clay minerals, including finely aggregated gibbsite and iron-oxides. The proportion of iron-oxide in the total fusion analyses of the soil is about equal to the total alumina: a feature which does not appear in any of the trumao soils of the other environmental zones.

The degree of leaching is considerably out of step with the present environment, but two factors may be contributing to this. In the first place the environment is one well suited to forest growth, yet because of its isolation, a forest cover has never appeared on these soils. The cyclic of plant nutrients has always been mainly in the hands of grass plants. Moreover, it has been the island custom for many centuries for the islanders to burn these natural pastures (see also Lisjanski, 1812; Beechey, 1831), with a resultant conversion of minerals into highly soluble forms that are relatively easily leached away.

6. Soil classification

Chilean pedologists, having little opportunity to work with soils developing under tropical conditions, have wisely refrained from trying to classify the soils of Easter Island. The more allophanic of these soils are recognised as being in some way distantly related to the Trumao soils of the mainland, but there the matter rests at present.

In the 7th Approximation (ibid, 1960) the soils appear to lie somewhere between Umbrandepts and Ustox lacking a dark horizon, but much nearer to the former group than the latter.

In the earlier New Zealand classification they might be regarded as very strongly weathered, very strongly leached Yellow Brown Loams; and in the latest classification of Pohlen (ibid, 1962), as 'very strongly enleached, alvic loams from strongly argillised andesitic ash'.

In the meantime it is probably adequate to designate these soils as very strongly leached, very strongly weathered, weak-to-moderately grass-melanised allophanic volcanic ash soils developed under a warm, humid but intermittently dry environment.

h) Ñadi soils

1. Environmental characteristics of Ñadi soils

"Ñadi" is an Araucanian word implying rather specific drainage conditions in the landscape and was used to indicate land that was swampy but with a firm subsurface, and hence transitable with care. In south-central Chile, between latitude 38°30'S and 43°00'S, "ñadi" areas invariable supported a forest cover; different aboriginal words were used for reed and rush-covered swamps, and for land that was not transitable when wet. Thus the original meaning of "ñadi" was a broad ecological concept that implied poor drainage conditions , subdued relief, dense forest cover and firm ground at no great depth below the surface. The word carries no specific implication of connection with volcanic ash, yet it is a fact that the "ñadi" condition of the landscape, in the concept of the Araucanians, came into existence solely as the result of the deposition of a mantle of volcanic ash on the landscape. The superficial layers of volcanic ash accept rainwater to the point where they become saturated, and since the hard cemented substratum greatly restricts vertical drainage, the mantle of volcanic ash remains wet and 'swampy' until rainfall decreases to the point where lateral drainage can cope with the input of water. Agronomists and pedologists recognise "ñadi" soils as being seasonally swampy soils since this is the condition which is most apparent when the land is cleared for farming, (CORFO, 1961).

"Ñadi" conditions first appear at about latitude 38°30'S, on broad floodplain remnants in the Province of Cautín, and occur with increasing frequency in the adjacent southern Provinces of Valdivia and Osorno, until about latitude 41°00'S, any transect across Llanquihue Province from the coastline to the Andean cordillera shows more than 50% of the lowland landscape occupied by "ñadi" conditions. (Fig.13). Ñadi soils occupy most of the flattish to undulating part of the landscape. They occur in association with better-drained soils derived from volcanic ash (Trumao soils) which occupy the more strongly undulating, rolling and hilly parts of the landscape; and are also in association with small areas of permanently wet soils in lowerlaying depressions without adequate egress for surface waters. In the southern half of the Province of Llanquihue, where the rainfall frequently exceeds 2000 mm per annum, excessive accumulation of acid forest litter produces a distinct peaty topsoil in many of the localities with Ñadi soils. Still further to the south, on Chiloé Island (in about latitude 42°00'S) peaty topsoil conditions become a general feature of all Ñadi soils in their natural state. In about latitude 42°25'S, near Mocopulli on Chiloé Island, in some of the flatter low-lands areas some Ñadi soils begin to show marked peat accumulation, and the forest vegetation becomes replaced by sedge communities, by Gleichenia - Pernettya - Baccharis associations, scattered Donatia cushions and with typical wet bog species such as Sphagnum, Tetroncium and Marsippospermum. In the extreme south of Chiloé Island, the distinctive pattern of the "ñadis" become lost, - completely submerged in the 'north-patagonian rainforest' (Schmithusen, 1956) dominated by Nothofagus dombeyi. In this latitude, (i.e. at about

43°00'S) the "ñadi" concept is no longer applicable; it is no longer possible to identify specific seasonally swampy areas since, with a rainfall in excess of 3000 mm per annum evenly distributed throughout the year, all the soils in the landscape are characterised by abundant humidity at all times.

Thus, in the north where they first appear, the patches of "ñadi" are conspicuous as being something different in the landscape; in the centre of their range, they are the dominant feature of the landscape, and at their southern limit they dissappear beneath peat bogs and cool temperate, very humid rainforest. Throughout this climatic range, no single plant species can be said to be characteristic of "ñadi" vegetation, and the dominant trees vary from north to south, and also vary with local soil conditions. By comparison with surrounding forest communities, the "ñadi" forests are, however, conspicuous for a preponderance of plants with xerophilous characteristics. The "ñadi" flora is rich "in Myrtaceae, Ericaceae, Berberidaceae, Juncaceae and Cyperaceae. The general aspect is of a stunted thicket, relatively dense, with a very dense herbaceous lower stratum of an abundance of mosses, especially sphagnum, and ferns" (Rodríguez, 1948). A further feature of the "ñadi" forests is the extreme shallowness of the root systems of the trees. Species commonly found in "ñadi" vegetation include Drimys winteri ('canelo'), Tepualia stipularis ('tepu'), Embothrium coccineum ('ciruelillo'), Ovidia pillopillo ('pillo-pillo'), Aristotelia chilensis ('maqui'), Lomatia ferruginea ('fuinque'), Lomatia obliqua ('radal'), Berberis buxifolia ('calafate'), Gunnera chilensis, Verbena corymbosa, Lomaria chilensis, Lomaria pennamarina, Baccharis saggitalis, Oldenlandia uniflora, Isolepsis vivipara, Juncus procera and Juncus planifolius. Less common generally, but sometimes of great local importance, are such species as Myrceugenia planipes ('patagua valdiviana'), Myrceugenia pitra ('pitra'), Myrtus luma ('luma'), Podocarpus nubigensis ('mañío'), Saxegothea conspicua, Pilgerodendron uviferum, Guevina avellano ('avellano'), Eucryphia cordifolia ('ulmo'), Desfontainea spinosa ('taique'), Fitzroya patagonica ('alerce'), Weimmania trichosperma, etc. In many areas, the most prominent tree is Nothofagus: colder situations favour N. antarctica ('nirre'), the more swampy situations favour N. nitida, while N. pumilio ('lenga') and N. dombeyi ('coigüe') are more common in the cooler and higher rainfall areas. Between Puerto Montt and Lake Llanquihue there formerly existed an area of "ñadi" entirely dominated by very large Fitzroya trees.

Towards the northern limit of the "ñadis", the mean annual rainfall lies between 1200 mm and 1500 mm with up to two months with less than 100 mm; but in the region where the ñadis attain their maximum development, the mean annual rainfall lies between 1500 mm and over 3000 mm with no months in the year with less than 100 mm. In this latter zone the precipitation during the three winter months frequently exceeds 1000 mm. Over the whole range of the "ñadis", the mean annual temperature lies between 10°C and 12°C. The warmest month (January) lies with the range 14°C and 17.5°C; while the coldest month (July) lies within the range 7°C and 8.5°C, (Almeyda, 1958). Cloud cover averages 60% over the year. According to Papadakis (1961), annual evapo-transpiration lies between 25 and 50 cm per annum, so that the excess precipitation theoretically available for leaching through the soil is in the range of 175 to 220 cm per annum. No actual evaporimeter data are available for the region of the "ñadis", but field observations suggest that in some cases the removal of the forest results in the soil conditions becoming wetter than formerly, and hence water lost by direct transpiration may considerably exceed that lost by direct evaporation.

Any study of Ñadi soils must begin by considering the origin of the typical landforms associated with these soils, and the probably manner of emplacement of the volcanic ash on this landscape. Recent drilling by petroleum exploration groups has shown that the shape of the bottom of this sector of the great Central Vale of Chile varies markedly. Usually the bedrock is micaschist, and this is covered with from 100 ft to over 4000 ft of sediments, mainly sandy and gravelly. The uppermost part of this filling material is clearly of glacial origin (Weischet, 1958), and the ñadis occur on flattish to very gently undulating landforms between morainic debris. There is evidence to suggest that the parent materials of the Ñadi soils were emplaced subsequent to the last glaciation; although buried Ñadi-like soils, probably dating from earlier glacial periods, have also been found.

Not all Ñadi soils are associated with glaciated landscapes. Those of the northern sector (e.g. Petrufquen soils) are found on old terrace landforms, while some of those in Chiloé Island are also associated with terrace formations and even with local lacustrine deposits. None of these landscapes are likely to be older than the ultimate glaciation.

The stratigraphic column of Ñadi soils is much abbreviated as compared with adjacent Trumao soils on more strongly rolling landforms, and there is usually no recognisable correlation of the stratigraphic sequence between the latter soils and Ñadi soils in the vicinity. There is also the problem of the method of deposition of the original volcanic materials. Usually the material is free of stones and gravel, although on Chiloé Island, Ñadi subsoils often contain very fine rounded quartz pebbles, especially common in the lower horizons. In Chiloé, it is easy to think of the soil materials as being emplaced by water, yet, apart from the fine rounded gravels there are no other indications of their possible alluvial origin. Moreover, the materials usually show a notable thickening towards the edge of the terrace (see fig. 13) which is difficult to contrive solely by deposition from water, and is almost impossible to imagine when there are several levels of terraces all apparently covered with the same kind of ash deposition and more or less following a common pattern of stratification.

A more feasible explanation is that the soil parent materials was probably deposited mainly in the form of "loess" rich in volcanic glasses, on the wide outwash plains of a periglacial zone. The presence of occasional rounded fine quartz pebbles in the material may indicate nothing more than the force of the wind, and the probability that the land surface was periodically frozen allowing the pebbles to roll for some distance. The source of these pebbles is never far distant: they are usually to be found in the sandy morainic deposits of the vicinity. A few cases have been noted where these pebbles have clearly been resorted by very local water movements, and this also is entirely feasible in a frozen landscape subject to periodic thawing and even solifluction.

The discrepancy between the depth of the volcanic materials on the ñadi plains and that on the Trumao-covered downland is probably a matter of distortion of wind currents by the latter topography, allowing thicker deposition of the wind-borne volcanic dust from more turbulent air. The fact that weak stratification is visible in the Ñadi parent materials, and very marked stratification is visible in the nearby Trumao parent materials, serves as an indication that the source of the dust was not consistent over the whole period of accumulation. Well-defined shower layers also occur in the Trumao soils, and in a few cases these shower layers can be traced, without break, into the Ñadi stratification, where it is found to be much reduced in thickness but virtually of the same basic composition.

As a tentative theory, then, one would be inclined to suggest that the Ñadi soil parent materials are mainly of aeolian origin, and that the great majority of them were deposited not earlier than date of the last withdrawal of the ice from this part of southern Chile. Older materials deposited in the same way at the end of earlier glaciations have been almost entirely destroyed by erosion of the lowland landscape associated with the cutting of new drainage channels during the various interglacial periods. The process of loessic accumulation did not cease immediately on the final retreat of the glaciers, but continued through the early part of the post-glacial period when the landscape was intermittently re-frozen; and was further prolonged, in some areas, to allow loessic deposition on the first alluvial terraces. The process probably finally ceased when the land was again clothed in vegetation.

Fragments of older Ñadi-like soils, some very rich in organic matter (and perhaps containing valuable pollen remains), are occasionally preserved in cemented ash beds included in morainic debris. Cemented ash beds of this type are thought to represent ash materials that fell on the glacier surface, gradually becoming incorporated in the glacial ice. This ash was subsequently released when the glaciers retreated, the deposited material cemented (apparently by silicates of calcium and magnesium), permitting the preservation of other materials present in the glacial ice. Amongst these were relatively large and irregular patches of frozen soil, ploughed up from the pre-glacial land surface by the advancing snout of the glacier. These are not so common in the moraines of the last glaciation, which was a relatively minor one, but are very common in the morainic materials of the penultimate glaciation. Thus, still cemented in relatively unweathered ash materials, we can still find soils dating from at least the penultimate interglacial period. Some of these fossil soils are so well preserved that it is possible to re-construct their original orientation (some are inverted and some are now at right-angles to their original position), and to find the thin iron-pan of the original 'B' horizon still intact. Many such relicts are not simply fossil volcanic ash soils, but are clearly fossil Ñadi soils. They deserve much greater investigation than they have had up to the present time. Still older soils are preserved in cemented ash materials associated with the second glacial period: they must represent fossil remnants of the landscape that existed during the first interglacial period, and are even more worthy of study.

2. General morphology of Ñadi soils

It is by no means easy to decide upon the critical general morphological characteristics of ñadi soils owing to the rather wide variation of the more conspicuous profile features. Most of the more conspicuous features are inherited characteristics, - the nature and arrangement of the various depositional strata, - and are hence not admissable as general morphological characteristics. However, irrespective of the inherited layering, all ñadi soils display:

- very dark coloured topsoils,
- a change in colour towards yellowish brown (ranging from dark yellowish brown to strong brown) at some point in the subsoils,
- an abrupt change from yellowish colours to rather pale brown or gray or reddish brown somewhere in the lower subsoil,
- rather strongly developed granular topsoil structures,
- rather weakly developed subsoil structures when moist and under natural conditions, which change very markedly on drying to very coarse regular subangular blocky structures, - often to well formed prisms,
- crispness of peds when moist, which becomes hardness on drying ,
- very weak incipient indications of mottling in the upper and lower limits if the subsoil under natural conditions (the degree of mottling contrasts oddly with the extreme seasonal wetness of these soils),
- development of more prominent mottles in the upper subsoil horizon in soils that have been thoroughly drained and farmed for many years, this feature is accompanied by compaction and clay accumulation in this horizon in extreme cases,
- slight to pronounced clayskin formation in the lower subsoil is a feature of most ñadi soils,
- accumulation of iron-oxide and related compounds either at the junction of the unconsolidated ash layers with the underlying consolidated substratum, or at some depth down in this substratum,
- very strong and very pronounced shrinkage fissure appears in the dried out road banks and ditch sides of most ñadi subsoils, these fissures isolate the dry prisms which often appear as irregular, unstable soil columns.

3. General chemical characteristics

Chemical studies of ñadi soils have been undertaken by CORFO and at this stage no published information is available.

4. Characteristics of typical Ñadi soils

From the large number of Ñadi soils that have been identified in Chile (Díaz, et. al., 1958; 1959), four have been selected as being reasonably representative of the group. Pitrufquén ñadi soils occur only at the northern

15 cm very dark brown (moist) friable granular sandy loam that is somewhat hard when dry;
20 cm dark brown (moist) friable, well-structured loam, also hardening on drying;
15 cm dark brown (moist) friable heavy silt loam to silty clay loam, well-structured and drying out to prisms with prominent shrinkage cracks;
20 cm strong brown (moist) very strongly structured but friable light clay loam giving prominent prisms with very wide shrinkage cracks when dry; peds have clayskins;
10 cm strong brown rather firm blocky heavy silty clay loam with marked clayskin development around the peds;
0.5 cm thin continuous iron pan,
On.. very dark grayish brown (moist) very compact and cemented gravelly coarse sandy clay loam.

Carel soils are often well farmed with the assistance of mainly phosphatic fertilizers and nitrogen. Some farmers apply up to 150 units of phosphate per hectare, along with 30 to 40 units of nitrate of soda. It is an excellent pasture soil; volunteer grasses include Holcus mollis, and many legumes (especially lotus) come in naturally. Appears to be well suited to high-producing rye-white clover pastures for dairying when adequately fertilized. Many farmers tend to overdrain their soils and summer production suffers accordingly.

iv) Calonje very fine sandy loam (Appendix, profile No.

Calonje soils are developed mainly on Chiloé Island under a somewhat moister environment than the preceding ñadi soils. They occur on terrace landscapes with a gently undulating to flattish relief, and formely supported a Nothofagus swamp forest.

These soils experience a mean annual rainfall of about 2000-2500 mm of which slightly over 40% falls in the winter months, and a little more than 10% in the summer months. Under natural conditions the soils do not dry out, but when farmed and intensively drained the soils may show signs of summer moisture deficiency. Mean annual temperatures are about 11°C, with mean summer temperatures of about 20°C and winter 7.5°C.

A typical soil profile shows:-

20 cm almost black (moist) friable but rather heavy fine sandy loam with a good granular structure;
10 cm very dark brown (moist) slightly firm fine sandy clay loam, well-structure and with 'crisp' peds;
8 cm dark gray (moist) silty clay with a few small stones (usually rounded quartz); friable and blocky but drying to prisms;
15 cm dark grayish brown (moist) firm light clay with no very distinct structure;

20 cm brown (moist) somewhat stony clay, firm and without any distinctive structure,

On.. compact olive (moist) gravelly loamy sand; gravels stained with iron-oxide.

5. Soil genesis

The inherited characteristics of Ñadi soils include an alluvial substrate which was either partly cemented at the surface before the ash mantle was emplaced or became rapidly cemented with silica during the early stages of ash accumulation; and stratified layers of volcanic ash consisting of fine andesitic materials, in part interlayered with coarser acidic shower materials. Coincident with the accumulation of the ash mantle, there must have been a change from cold, relatively dry steppe conditions, to humid cool-temperate conditions in which forest became the dominant plant cover, (see also Auer, 1958). In many places the alluvial material below the ash mantle shows of an old erosion surface.

The acquired characteristics of Ñadi soils include:

- the relatively rapid weathering of the finely divided volcanic glass to allophane clays, and a further change in the older ash layers in the direction of halloysite, kaolinitic and perhaps gibbsitic clays;

- moderate to strong leaching, strongly conditioned by a tendency for accumulation of raw, acid forest litter on the soil surface in the southern part of the "ñadi" region, resulting in the formation of sesquioxide-rich bands in region of textural discontinuity in the subsoils, and

- strong reducing conditions which develop when the soils are saturated by excess rainfall.

The existence of strong reducing conditions can be demonstrated in the field, and can be inferred from the characteristic smell of the subsoil clays. It is, however, a peculiarity of Ñadi soils that the soils seldom develop typical gley morphology: subsoils are rarely mottled and never exhibit the greenish-gray or bluish-gray colours characteristic when strong reducing conditions are operating in soils of more normal silica/alumina composition. It would seem as if the high allophane content of the soil precludes the development of typical gley morphology; instead of strong mottling or gleying, many Ñadi soils show a bright brownish-yellow horizon immediately above the silicified substratum, and sometimes similar colours develop elsewhere in the soil profile, in the vicinity of iron pans. In part, this characteristic is associated with a particular kind of volcanic material in which fine pumice fragments may still be discerned, but nevertheless it is about the only feature of the soil profile that might be regarded as an expression of strong reducing conditions. The bright brownish-yellow horizon appears to contain considerable allophane, yet shrinks markedly on drying forming vertically elongated prisms and swells again when wetted to form an almost impermeable layer. It is this layer that is, above all, responsible for the appearance of 'perched' water tables in Ñadi soils during the first heavy rains of winter after the slightly drier conditions of summer and autumn. The surface of this layer swells and impedes downward movement of the rainwater. A second 'perched' watertable occurs at the surface of the cemented gravelly substratum, and this lower watertable gradually thickens until it becomes continuous with the upper one, leaving the whole profile thoroughly waterlogged.

6. Soil classification

Physiologically, the Ñadi soils are Allophanic soils with restricted drainage conditions. Morphologically, they are not so readily separated from the better drained Allophanic soils of the region, and many intergrades are known. Since there is no characteristic expression of gleying to denote the intensity of reducing conditions seasonally present in these soils, impedence of drainage has often to be inferred from the depth of the ash mantle, the nature of the strata in the ash mantle, and the presence and position of horizons of silica or sesquioxide accumulation. Where the natural vegetation is undisturbed, this provides an infallible guide to the Ñadi soil conditions in the north and centre of the "Ñadi" zone: but in the south, particularly in the island of Chiloé, where leaching is more intense and is more strongly condition by mor-forming vegetation, the composition of the indigenous plant cover is a less useful guide. In Chiloé, the majority of the Ñadi soils are virtually podzolised Gleys, but without the typical expression of gleying. They grade towards soils which behave like typical Gleyed Podzols, yet so strong is the influence of allophane that none of the typical morphological features of the Gleyed Podzols is expressed in the soil profile. In the south of Chiloé, these peculiar soils become the chief component of the regional soil pattern, and one can only classify them at the present juncture as 'very strongly leached Allophanic soils of the humid, cool-temperate region'.

In seeking global counterparts of these soils, the search can be limited 'a priori' to regions where the landscapes are mantled with volcanic ash, thinly spread over an impervious substratum; where temperature and rainfall patterns are similar to south-central Chile; and where the natural vegetation is evergreen forest with a high proportion of species pre-disposed to the formation of acid mor. Ñadi soils are not found in New Zealand, although the climatic equivalents and a comparable plant cover do exist on the western coastal lowlands of the South Island. Here, at the exact latitude of northern Chiloé, both climate and vegetation approximate closely to northern Chiloé (Godley, 1960), but there is no mantle of volcanic ash: in place of Ñadi soils, the 'pakahi' Podzolised Gleys are found (Gibbs, 1950).

Japan is another country where counterparts of Ñadi soils might occur but none of the published descriptions of the volcanic ash soils with restricted drainage conditions indicate close equivalence with Ñadi soils. Kanno (1956) has made a study of a lowland soil derived from volcanic ash that has sufficient impedence of drainage to permit it being used for rice growing. In this soil the subsoil clays consisted mainly of hydrated halloysite and illite, with varying amounts of allophane, gibbsite, vermiculite and chlorite. There is no information yet available on the nature of the subsoil clay in Chilean Ñadi soils but a sample has been collected from the prominent brownish-yellow horizon of one Ñadi soil and forwarded to New Zealand for analysis.

j) Trumao soils on steep slopes and related steepland soils

More than 50% of the Chilean allophanic volcanic ash soils occur on steep slopes within the limits of the Andean ranges: these are the trumao steepland soils, and they usually found complexly associated with other steepland soils and lithosolic soils derived from the country rock.

In many parts of the Andes, the mantle of volcanic ash is deep and practically continuous over the whole of the rugged landscape, but in other parts, the ash mantle has been torn and reduced by man-made or natural erosion so that only a small section of the steepland complex of soils is actually derived from volcanic ash.

Volcanic ash as a parent material of steepland soils being to make its appearance in the Andean ranges at about latitude 36°C, and a more or less complete mantle of ash is present from about 38°S and extends virtually unbroken (except by local erosion) to 47°S. Thus this important feature of Andean soils covers a latitudinal range of nearly 10°. On most soil maps of Latin America, this sector of the Andes is usually shown as possessing mainly lithosolic soils: this is far from the truth of the situation at the present time, for this mountainous landscape is occupied mainly by steepland soils (as defined by Gibbs, 1962) derived from volcanic ash and not by lithosols, although another century of human (agricultural) endeavour may well establish the validity of the earlier soil maps, for in some areas the man-induced erosion is truly horrifying.

1. Environmental characteristics of trumao steepland soils

The landforms associated with these soils range from moderately steep to precipitous, but steep (28° to 33°) and very steep (33° to 37°) slopes predominates. The original landscape has been carved in hard Andean rocks (mainly andesites, granites and indurated sedimentary rocks older than Tertiary) by normal erosional cycles. The predominance of steep landforms is due to the Late Tertiary history of uplift and tilting of land surfaces, associated with the Andean orogeny. On this unpromising dissected basement volcanic ash has successfully accumulated to a surprising depth.

Many of the Chilean volcanoes are currently active from time to time, and it is comparatively easy to study the mechanics of ash accumulation. The formation of an ash mantle on the rugged landscape is clearly associated with the regional climate and plant cover, and with the nature of the ash being deposited. North of latitude 36°S, the climate is too dry to permit the development of a closed forest cover, and in the absence of a dense forest vegetation all the finer ash reaching the soil surface is removed by wind and water, leaving only some of the coarser materials (especially those that arrive as a result of a paroxysmal eruption, when large amounts of coarse and fine material may arrive in a short space of time). A certain degree of humidity is necessary in the environment, not only for the establishment of a forest cover to protect the newly deposited ash, but also to promote rapidly the weathering of the volcanic glasses to form some amount of amorphous materials for binding the ash together. In the extreme south, below latitude 46°S, there is often an adequate forest cover but it is mainly a deciduous one and normal conditions are so cold that weathering of the volcanic glass is comparatively slow in commencing. In all latitudes, the ash mantle may be reduced or almost absent in the immediate vicinity of the volcanoes. The conical slopes of most volcanoes are, usually built up of very coarse ash and cinders, interlayered by lava flows. Beds of fine ash are usually absent except where protected by capping of a younger lava flow (fig.). However, even at some distance from the actual volcanic cone, the ash mantle may be but poorly developed. In part this is likely to be due to the repeated destruction of the forest cover (by noxious gases, or by fires originating from molten lavas) which removes one of the conditions requisite for steady ash accumulation.

Studies made during the eruptions of Puyehue (1960); Calbuco (1961); and Villarrica (1962, 1963) on the building up of ash beds (Wright and Mella, 1963) showed that during each of these brief eruptions amounts ranging from a few millimetres to over 6 cm of fine volcanic ash settled on the landscape. In most cases, this settled chiefly on the leaves of the vegetation, and in heavily forested areas little ash reached the soil directly. In every case, rain fell within one week of the date of ejection of the ash, and after this rain the ash dissappeared from the foliage (but remained lodged in the axils of the branches and trunks of the trees) and presumably reached the soil surface, although only in rare cases could be fresh ash be recognised on the soil surface without microscopic examination. In many cases a thin film of fresh ash could be detected running down the tree trunk during the rainy period and there is the possibility that there is a relatively greater concentration of fresh ash on the soil near the base of the actual trees than elsewhere in the forest.

Weathering of the ash minerals was evident within one month, and by this time frésh ash material could be detected in surface soil samples at a depth of from 2 to 3 cm below the actual soil surface; presumably the processes of incorporation by soil animals was already operating strongly. It is feature of all forests in the volcanic ash region of Chile, that the main rooting zone of the trees and bushes is extremely close to the surface. This may reflect the much better base status of this part of the soil profile resulting from the periodic addition of fresh mineral matter to the soil surface. The rooting system of these forests characteristically consists of a dense tangle of large and small tree roots in the uppermost 20-30 cm of the soil, and many of the roots form root-grafts, linking the whole root system into a firm but superficial network. This root network plays an important role in the stability of these forests on steep slopes (see also Wright & Mella, 1961). Not all forest species concentrate the majority of their roots in the extreme surface of the soil; there are distinct differences between the rooting habit of, say, ulmo (Eucryphia cordifolia) and coigüe

(Nothofagus dombeyi), but even trees like the latter that are often of a rather deep rooting habit show a tendency for superficial proliferation of their roots in volcanic ash soils.

The most abundant type of forest on the steepland trumaos is an evergreen formation composed of laurel (Laurelia serrata), olivillo (Aextoxicum punctatum), canelo (Drimys winteri) and Nothofagus spp. The latter tend to seggregate as pure stands and it is common to find coigüe trees occupying an almost pure belt at some elevation on the mountainside. The deciduous species of Nothofagus (ñirre, N. antarctica, and lenga, N. pumilio) show the same tendency in the more southern Andean ranges. Araucaria and Fitzroya occur on these soils and also tend to seggregate as pure forests.

Above the forest upper limit, the plant cover consists mainly of low bushes, in which members of the Berberidaceae, Vacciniaecae, Epacridaceae are well represented; and at still higher altitudes some tussock grassland may appear. Under this marginal sub-alpine vegetation, the depth of the ash mantle decreases sharply: presumably the very cold, windswept sparsely-vegetated environment is less suitable for accumulation of volcanic ash.

The depth and composition of the ash mantle varies widely from place to place. An average depth on slopes of between 30° and 35° would appear to be about 3 metres; with rather less accumulation on short convex slopes, and considerably more on long, somewhat concave, slopes. The maximum depth measured was 8 metres, in the Golgol valley. The 'stratigraphic column' of the ash mantle varies in accordance with the pattern of volcanic activity of the immediate region, but most soil pits dug on steep hillsides showed repeated layers of fine and coarse materials ranging from fine andesitic ash (most common), to coarse rhyolitic and siliceous pumiceous sands, to black basaltic sand (least common) and fine basaltic scoria (quite rare). The transition from one strata to the next in the column is usually abrupt, except in the case of andesitic ash materials of slightly differing grades and mineral composition where the transition may be more gradual.

Climatic data for the territory of the steepland trumaos is very deficient. It is known, in a general way, that the mean annual rainfall ranges from about 2500 mm to over 5000 mm; that much of the winter precipitation is in the form of snow; that the summer precipitation is not much above 20% of the total annual precipitation; that the mean annual temperature range is approximately 5°C to 13°C; that winter temperatures have a mean between 9°C and zero; and that mean summer temperatures are probably in the vicinity of 20°C. In general these soils are found under a cool-to-cold, humid-to-superhumid type of environment.

2. General characteristics of trumao steepland soils

It is almost impossible to describe these soils in general terms owing mainly to the great variation in inherited characteristics.

The chief features of the profiles held in common by these soils include an intensely black or very dusky reddish black topsoil, usually of no great depth (15 to 25 cm); pronounced humic staining of the upper subsoil strata and horizons; very marked topsoil friability due to the abundance of roots and perhaps the 'rocking' action of the forest cover; abundance or rather rounded aggregates in the topsoil due to the intense activity of insects and earthworms, - even at the highest elevations; increasing compaction with depth; also increasing clay content, stickyness and plasticity in depth (except where coarse pumiceous sands intervene in the stratigraphic column; yellowish brown subsoil colours that grade with depth to reddish brown or reddish yellow colours (except where basaltic sands intervene in the stratigraphic column).

3. General chemical characteristics

Many samples of these soils have been collected but no analyses are yet available.

4. Characteristics of typical soils

No detail soil profiles are quoted in the Appendix since it is still too soon to say which are the more typical soils of the group. The soils described below have been recognised in the field as being soils covering an important extent of many mountainsides. Their actual boundaries have not yet been mapped since these soils are often more of interest to foresters than to agriculturalists, and the Forestry Organisations of Chile are not yet equipped to make soil maps; nor does the Agricultural Ministry have men or materials available to undertake the work.

i) Atacalco steepland soils

These occur near the northern limit of the steepland trumaos, and are formed from ash beds and shower layers derived mainly from Chillán and Antuco volcanoes. The soil parent materials are mainly andesitic volcanic ash, perhaps somewhat more basic than normal, with a fair amount of basaltic sand in defined strata. The ash mantle is about 75% complete on slopes up to 30°, and about 45% complete on slopes over 30°. The terrain is very steep and mountainous.

The climate of the region is between sub-humid and humid, with a mean annual precipitation of about 2500 mm but without effective rainfall during three months of the year; the mean annual temperature is probably about 14°C.

A common moist soil profile shows:-

20 cm very dark brown loamy sand, friable and with a very weak granular structure, without plasticity or stickyness when moist, distinct boundary;

20 cm dark reddish brown very friable slightly sticky and plastic sandy loam with weakly developed blocky structure and diffuse lower boundary;

35 cm strong brown friable, slightly sticky and moderately plastic sandy loam with a moderately developed blocky structure and distinct lower boundary;
30 cm brown loam to silty clay loam, more compact than horizons above and of firm consistency, weakly developed coarse blocky structure and peds contain some fine pumiceous gravel, lower limit abrupt;
8 cm dark gray loamy sand of basaltic origin;
25 cm pale yellowish brown compact pumiceous sandy loam ;
15 cm very dark reddish brown loamy sand, probably basaltic;
55 cm dark brown greasy silty clay loam, rather compact;
120 cm brown very well-structured clay loam with high plasticity;
10 cm reddish brown coarse sandy clay loam with lumps of weathering basaltic scoria,
On.. slightly weathered granitic rock.

Atacalco steepland soils are mainly occupied by second-growth forest with occasional patches of the original evergreen broadleaf forest. In many places fires have repeatedly destroyed the forest cover and the soils are eroded down to bed-rock. This largely accounts for the incomplete state of the ash mantle mentioned above. Atacalco soils have an altitudinal range of from 1000 m to about 2200 m and their potential value to the Nation is obvious as Forest Reserve: they are by no means suited for agricultural soils.

ii) Momolluco steepland soils

Momolluco soils are developed mainly in Cautín Province in the Andean ranges that lie within the influence of Llaima volcano, although ash contributions from Lonquimay, Tolhuaca and other nearby volcanoes are almost certainly represented in the ash mantle. The ash mantle is 100% complete under natural conditions, but has been severely destroyed by erosion in the vicinity of farming settlements. The terrain is steep to very steep, for the most part, and these soils are found over an altitudinal range of about 1200 m to nearly 2500 m.

The climate is decidedly humid with probably about 4000 mm annually, and no very marked dry season. Even in summer the soils are usually moist. Mean annual temperatures are in the vicinity of 10°C, and the winter months are very cold with frequent frosts and occasional snowfall.

A common moist soil profile shows:-

10 cm very dark gray basaltic gravel (scoria) and sand;
15 cm dark reddish brown loamy sand;
40 cm very dark yellowish brown coarse loamy sand;
30 cm pale yellowish brown pumiceous loam with some indication of structural aggregation and very slight plasticity but no stickyness;
50 cm brown silty clay loam, greasy but rather compact;
110 cm yellowish brown fine sandy loam with occasional pumice fragments, compact and almost cemented;

70 cm dark reddish brown loamy sand, possibly basaltic;
5 cm very dark reddish gray cemented basaltic scoria
115 cm brown very well-structured clay loam, firm and very plastic;
10 cm brown sandy clay loam, well-structured, sticky and plastic with an abundance of coarse sand grains,
On.. weathering granite.

Momolluco soils are highly erodable, readily forming giant slips and debris avalanches when the natural forest cover is tampered with: even logging of the forest on these soils needs to be done with great care. The main forest tree is Araucaria, a most valuable timber tree, and it is very sad to see the criminal carelessness of the lumber companies exploiting this tree, and the careless use of fire to clear patches of land for farming by squatters who often follow behind the timber extraction operations. Ideally, this soil should fall within the category of 'watershed reserve' and be left strictly alone to regenerate what it can be of the original forest.

iii) Chanleufu steepland soils

Chanleufu steepland soils are found mainly in Osorno Province on steep to very steep slopes in the vicinity of Casablanca and Antillanca volcanoes, and on the southern side of the Golgol river valley. This soil is well seen on the road through the Puyehue National Park and has been described in detail by Díaz et. al., (1959). The natural vegetation of this soil is a mixed evergreen broadlef forest in which laurel, olivillo and ulmo are prominent, with some almost pure stands of Nothofagus dombeyi and N. antarctica.

The soils are formed from up to 18 thin strata of volcanic ash ranging from basaltic sand to acidic pumiceous rhyolitic sand, interleaved by beds of very fine andesitic ash. The latter, almost everywhere, forms the main bulk of the profile strata, and is the chief subsoil material. All these materials are clearly of subaerial origin, but some of the layers appear to have been emplaced as mud-showers.

The climate associated with this soil is markedly humid and rather cool. The mean annual precipitation amounts to (probably) over 4500 mm of which part falls as snow in winter. The summer rainfall amounts to about 16% of the total rainfall. The mean annual temperature is probably less than 10°C.

A typical profile shows:-

10 cm very dark brown finely granular silt loam, friable and slightly sticky and plastic. (field pH, 5.3);
10 cm very dark gray moderately blocky sandy clay loam, that is fairly friable but moderately sticky and plastic. (field pH, 6.0);
7 cm black coarse sandy clay with conspicuous coarse white weak, fine subangular blocky structure and much stronger stickyness and plasticity than horizon above. (field pH 5.5);

4 cm very dark gray brown friable coarse sandy with neither structure nor stickyness, nor plasticity. (field pH, 5.5);
8 cm pale olive brown coarse sandy clay with reddish yellow fragments of weathering scoria, weak fine subangular blocky structure and moderate stickyness and plasticity. (field pH, 6.2);
7 cm very dark gray brown friable sandy clay with no visible structural aggregation but strongly sticky and plastic. (field pH, 6.1);
12 cm dark reddish brown cemented gravel. (field pH, 5.3);
20 cm very dark gray very weakly cemented gravel, mainly basaltic scoria but with some coarse white sand grains. (field pH, 6.4);
20 cm rather closely banded dark yellowish brown and yellowish brown very fine sandy clayloam, varying in hardness from weakly cemented to slightly hard (even in moist condition). (field pH, 6.3),
On.. very dark gray sand and gravel composed of scoriaceous lava fragments, mainly closely packed and hard. (field pH, 6.2).

Chanleufu soils are relatively young soils, yet are too old to be classed with Recent Volcanic soils. They are unsuited to agriculture and are best considered as Forest Reserve soils or, where they have been cleared by over-enterprising farmers, as soils that should be allowed to regenerate in forest. They eroded very severely and most spectacularly on the occasion of the 1960 earthquake, and destroyed most of the communications in the lower Golgol valley but it was most noticeable that only the cleared slopes formed massive landslips while the same soils under forest only produced local debris avalanches.

iv) Peulla steepland soils

Peulla steepland soils are found near the head of Lake Todos Los Santos and extend southward for a considerable distance towards Palena. Many different volcanoes have contributed to their origin, including Osorno, Calbuco, Casablanca, Hornopiren and, possibly, Tronador. They are developed mainly under Nothofagus forest (N. dombeyi and N. antarctica) in a very wet and cool climate with over 4000 mm precipitation and mean annual temperatures lower than 10°C.

A common profile shows:-

25 cm black loamy coarse sand, friable and weakly granular in structure but non-sticky and only very slightly plastic;
20 cm very dark brown coarse sandy loam, friable and moderately blocky in structure, slightly sticky and plastic;
45 cm reddish brown coarse sandy loam grading to sandy loam that is friable, well structured and slightly sticky and moderately plastic;
20 cm dark yellowish brown rather compact pumiceous loamy sand that is slightly sticky and plastic;
40 cm very dark brown very greasy silty clay loam with a very well developed coarse angular blocky structure, and moderately sticky and plastic;

80 cm dark yellowish brown pumiceous sandy clay loam;
20 cm dark gray slightly cemented basaltic sand;
On.. alternating bands of coarse and fine basaltic sand, with many of the finer textured bands distinctly cemented.

Peulla soils are unsuited for farming since they occur only on very steep slopes and on precipitous mountainsides. They erode readily when the natural forest is removed, and should be kept under Forest Reserve administration, or as National Parkland.

v) Huemules steepland soils

Huemules steepland soils occur mainly in Aisén Province and mainly to the south of the Simpson river valley. They are developed on very steep to precipitous mountainsides that, not withstanding their extreme angle of slope, have a mantle of volcanic ash up to 150 cm in depth, and more or less continuous except where destroyed by erosion following destruction of the natural forest cover. Of the total depth of this ash, more than half is formed from pumiceous rhyolitic sand and fine gravel; the remainder consists mainly of very fine andesitic ash. Usually at least six different ash and shower strata are represented in the stratigraphic column of the ash mantle. Towards the northern limit of this soil, there is the additional appearance of a thin band of black basaltic volcanic sand.

The natural plant cover on these soils is mainly Nothofagus forest, including N. dombeyi on the lower mountainsides, and N. pumilio and N. antarctica at the higher elevations.

The climate is cold and very wet, with the annual precipitation in the vicinity of 4500-5000 mm; of this amount about one quarter of the total may fall as snow. The mean annual temperature is probably not higher than 6°C.

In the case of Huemules steepland soils the basement rock is granite. Usually this rock has a comparatively unweathered surface. The ash mantle rests directly on this rock, and when the natural forest is destroyed by fire the whole of the ash mantle may slide smoothly off the mountainside, leaving bare rock faces of wide extent, and these offer little foothold for fresh forest seedlings.

A common profile shows:-

15 cm very dusky red, peaty coarse loamy sand with a well developed granular structure, friable, and very slightly sticky and plastic;
20 cm dark yellowish brown gravelly (pumice) loam, friable weakly structured, and slightly sticky and plastic;
30 cm dark brown slightly gravelly sandy loam, rather firm and perhaps weakly cemented, slightly sticky and moderately plastic;
50 cm dark reddish brown sandy clayloam, firm, very well structured (coarse blocks) and moderately sticky and moderately plastic;

30 cm dark yellowish brown coarse loamy sand with a very few fragments of slightly weathered granite in the lower part ;
2 cm yellowish brown coarse sandy clay,
On.. hard granitic rock.

Huemules steepland soils are certainly unsuited for agriculture and it apparent from the amount of erosion that has already occurred in Aisén Province on these soils that all agricultural endeavour needs to be kept at a considerable distance from these soils. The main danger is fire. Fire is employed by most of the small farmers on the valley bottom soils, as a means of clearing away unwanted invading shrubs and trees from their pastures. Owing to the rugged nature of the terrain, it has proved almost impossible to control the lighting of these fires during the summer and autumn when the vegetation is in its driest condition. In an exceptionally dry year, or in years when the quila bushes (Chusquea spp.) flower and subsequent dry out (this happens with about a 20 year cycle), escaped farmers fires may travel for tens of kilometers, destroying the natural forests of the mountainsides sufficiently to allow the erosive forces to begin their work. Within a few years, the whole of the ash mantle may be stripped from these mountainsides; and much of the alluvial farmland at the foot of the mountainsides overwhelmed in mud-slides, rock-slides and gravel fan debris. Huemules steepland soils and many similar steepland allophanic volcanic ash soils should be rigorously preserved for forestry use only, and even under Forestry Control the amount of timber exploitation permissible must inevitably be slight and very well planned.

5. Soil genesis

Allophanic steepland soils derived from volcanic ash ('Trumao Steepland soils') are a special category of the steepland soil group first proposed by Gibbs (1954). They are very similar indeed to the steepland soils related to Yellow-Brown Pumice soils and Yellow-Brown Loams described from New Zealand (Gibbs, 1962).

In both Chile and New Zealand, they exhibit few of the normal signs of being constantly subjected to soil movement that is a feature of most other kinds of steepland soils. They are much deeper than normal steepland soils and they owe their origin more to the addition of volcanic ash to the surface than to the progressive weathering of the basal rock and to the accumulation of rock weathering products. As was shown in the introductory remarks, in Chile, allophanic steepland soils from volcanic ash cannot form where there the plant cover is inadequate or not in continuous occupation of the mountainsides; nor can they form where the climate is too dry to permit the development of a complete and permanent forest cover. Thus special conditions are involved in their genesis from the outset.

Because they are relatively very deep and porous soils, bound in place by a forest root network, they are not so vulnerable to erosive forces as other kinds of steepland soils. Under natural conditions, seldom does the intensity of rainfall exceed the capacity of the deep, porous soil to store (and subsequently slowly release) the rainwater. Under natural active conditions soil movement is minimal, and there is little evidence of soil creep and soil slumping. Neither, because of the protective network of tree roots, do gullies or landslips readily develop in these soils under natural conditions. Tunneling and 'under-runners' are more common than surface erosional phenomena.

Yet for all their apparent stability, these steepland soils are potentially highly unstable. Even very modest interference with the natural conditions produces debris avalanches (as defined by Sharp, 1938), and small landslips. A forest fire that destroys only a relatively small proportion of the trees has even more serious effects, and results to the development of larger landslips and more frequent incidence of debris avalanches. Complete clearance of mountainsides to permit establishment of pastures produces large scale erosion and results in the destruction of much valuable agricultural land on the adjacent valley bottoms, and even on the more distant lowland plains. Under extreme stress, as when severe seismic shocks are experienced the whole ash mantle on complete mountainsides may show signs of instability; many cleared hillsides simply collapse in a welter of mud-slides, catastrophic landslides, debris avalanches, etc.

The elements of instability are latent in the nature of the soil. The soils are highly stratified, each layer lying unconformably on the next. Some layers are pumiceous and are capable of absorbing a very large volume of water in their porous material. Some layers are basaltic sands which dry out very rapidly. Between these two diverse materials, there is usually a sandwich of fine andesitic ash weathered to a stage when it is composed mainly of amorphous allophane. Each of these materials may display weakness under certain conditions. The pumice layers, when filled to capacity with rainwater, add greatly to the weight of the load resting on the mountainside; the basaltic sand, when dry, is loose and runs freely, so that during a summer gale large trees overturn and the ash mantle is ruptured usually at this sand layer; the allophane-rich andesitic ash layers, when moist or wet, form a greasy or slippery lubricating horizon which is probably the chief cause of the spectacular erosion thattakes place on farmed mountainsides. In many ways it is quite remarkable that the forest root network can sustain so successfully the ash mantle, in the face of the grave physical weaknesses in the stratigraphic composition of the mantle.

Despite the elements of instability inherent in the system, these steepland soils under neutral conditions are nevertheless sufficiently stable to record a large measure of the zonal impress of soil formation. For example, where the rainfall is high, soil profile show abundant signs of leaching. The processes of soil melanisation appear to function normally; as do also the soil weathering processes. True, the soil profiles may show unusual features due to the fact that the movement of water through the soil has a strong lateral component, and soluble elements lost from the upper part of the slope are prone to re-emerge at points lower down the slope; - introducing the concept of 'flushing' in the soil process. Highly siliceous soils may show entirely normal (but rather thin) leached A_2 horizons of very low base status towards the top of the mountainside, whereas at lower elevations the same kind of bleached horizon may again be present in the profile, yet may have a relatively high base status due to the flushing process which is responsible for the return of soluble compounds to the soil surface. In some cases these areas of soil enrichment are well picked out by the distribution of the species of which the forest is composed. Again, they can often be recognised in the pattern of the plant associations developing on cleared and susequently abandoned hillsides.

6. Soil classification

Steepland soils are often dismissed as Skeletal soils or Lithosols - or even worse, lumped as Miscellaneous Land Types. They are rarely examined in detail and accorded a place in their own right. Nor, since their formative environment is entirely dominated by the extreme steepness of slope, can they be readily related to other soils developing on land of more gentle relief within the same general climatic regime. Hill soils can be related to easy land soils with little difficulty, but steepland soils have too many significant points of difference to allow this facile solution. In the case of allophanic steepland soils in Chile and New Zealand, they certainly cannot be considered either as Skeletal soils nor Lithosols.

The term 'Steepland soils' was coigned in New Zealand to mee the need of a descriptive term for soils occurring on steep and very steep slopes that were neither skeletal soils, lithosols, nor regosols. It was used to designate steeply sloping soils that possessed, to some degree, a mantle of weathering rock and it proved to be especially apt in situations where this rock waste mantle was augmented by accumulation of volcanic ash. Steepland soils are very common in the mountain ranges of New Zealand, even in places far removed from the influence of volcanic ash, and this is probably a of the fact that grazing mammals were entirely absent from the soil environment of New Zealand until historic times. Steepland soils are also very common in humid tropical lands with youthfully dissected landforms. In the humid tropics it is often the steepland soils that are the main stay of the population who grow their subsistence crops by a system of shifting cultivation, making skillful use of various aspects of the soil process (Wright and Twyford, 1957).

The semi-popular term 'steepland soils' has been replaced by more precise nomenclature in the latest New Zealand soil classification (Pohlen, 1962; Taylor and Pohlen, 1962). Steepland soils of the old classifications are now referred to the skeliform or skellic class, and are considered to belong mainly to the clinic subclass, where there is some rejuvenation by down slope movement. The allophanic steepland soils of New Zealand are referred to as clinic-alvic and clinic-subalvic, - the latter name being used for steepland soils mainly derived from pumiceous volcanic ash - rather than alvic-clinic soils, and this is a further recognition of the remarkable stability of these soils under natural conditions.

k) Intergrades between Trumao soils and other soils groups.

1. Intergrades to Recent Volcanic Ash soils

General features

Trumao soils show an appreciable coarsening of textures along any radius towards the volcano from which their parent ash originated, and at some point along the transect the typical features of trumao soils are lost by merging into ash materials of the most recent of the eruptions. The inner limit of the typical trumao soil and the outer limit of the Recent Volcanic ash soils is characteristically very difficult to define accurately because the junction usually occurs in steep, mountainous country. Under optimum conditions it is generally possible to define the boundary where there is a superficial deposit of recent volcanic ash greater than 10 cm in thickness, but more usually one can only indicate the approximate region where recent volcanic ash makes its appearance in superficial pockets scattered here and there over the steep slopes.

There is thus a distinct category of soils intergrading to Recent Volcanic Ash soils. They are usually of little importance agriculturally, but since they do have much higher plant nutrient reserves, these soils are of some interest to foresters. In the field, these intergrading soils can be identified by their similarity with normal trumao soils of the region with the addition of a thin superficial layer of very coarse sand or fine gravel, often including many scoriaceous or pumiceous fragments, some of which have the fusiform shape of miniature volcanic bombs or lapillae.

In Chile the commonest of these intergrading soils are formed from andesitic ash materials, but siliceous, rhyolitic and pumiceous materials, and also fine basaltic scoria, are not uncommon.

Typical intergrades

Four typical intergrades are described below in general terms, and more complete descriptions are given in the Appendix.

i) Chillan sand, intergrading to Santa Barbara sandy loam. (Appendix, profile N° 58)

This soil is found at a distance of from 5 to 9 km. from Chillan volcano. It is developed mainly on moderately steep to steep slopes, under evergreen forests of Nothofagus with locally dominant Podocarpus and Libocedrus. The mean annual rainfall of the region is probably close to 3.000 mm, and mean annual temperatures are about 13°C.

A typical soil profile shows:-

10 cm dark reddish brown (5YR 3/2, moist; brown, 7.5YR 4/4, dry) coarse sand, with fusiform fragments of black scoriaceous gravel,

5 cm dark brown (7.5YR 3/2, moist; brown, 7.5 YR 4/4, dry) coarse sand and loamy sand,
On.. typical Santa Barbara profile, but textures ranging from loamy sand to coarse sandy loam over uppermost 100 cm.

This soil intergrade appears to be stable under the natural forest but the uppermost 15 cm is highly erodable when the forest is cleared for agriculture; in many cases the whole of the recent ash has been stripped off the cleared slopes and accumulates along the foot of the slope, burying the fence posts almost up to their tops.

ii) Lonquimay coarse sand and gravel, intergrading to Cautin sandy loam (Appendix, profile N° 59)

This soil is developed in the vicinity of Lonquimay volcano, mainly on steep slopes covered with Araucaria forest. It occurs at an elevation of about 1.500 m, and is developing under a mean annual rainfall of about 3.000 mm, and mean annual temperatures of about 12°C.

A typical soil profile shows:-

8 cm black (5YR 2/1, moist; very dark gray, 7.5 YR 3/0, dry) coarse sand and scoriaceous gravel,
15 cm light gray very fine scoriaceous gravel,
On.. strong brown to yellowish brown loamy coarse sand grading to sandy loam at 100 cm.

This soil is a very valuable forestry soil, but proves to be highly erodable when the natural forest is cleared. It is undoubtedly very fertile, but common sense dictates that this is one of the fertile soils that should not be opened up for agriculture of any description. Unfortunately, small farmers are appearing on this soil, - families from the lowlands seeking to establish their right to a patch of land of their own - and the usual destruction of National resources is starting in the region.

iii) Villarrica coarse sand, intergrading to Pucon loamy sand (Appendix, Profile N° 60)

These soils are found on the lower planeze slopes of Villarrica volcano, under Nothofagus forest; they are developed under a mean annual rainfall of about 2.800 mm and a mean annual temperature of about 12°C. Topographically, they occupy slopes ranging from strongly rolling to moderately steep.

A typical profile shows:-

5 cm dark reddish brown (5YR 3/2, moist; light brownish gray, 10YR 6/2, dry) loamy coarse sand,
13 cm brown to dark brown (7.5YR 3/2-4/4, moist; pale grayish brown, 10YR 5/2, dry) gravelly loamy sand,
On.. typical Pucon loamy sand profile.

These soils are very fertile, and on land of rolling relief can be cleared of the native forest and farmed very successfully. Volunteer clovers and pasture grasses of a good type rapidly establish on the cleared soils. On slopes greater than 20° they prove to be highly erodable soils, and should be left under the natural forest cover.

iv) Antillanc stony sand, intergrading to Chanleufu soils (Appendix, Profile N° 61)

These soils occur mainly on the upper slopes of Casablanca and Antillanca volcanoes in the Province of Osorno. Their natural plant cover is Nothofagus forest, and they are developing under an annual rainfall of about 3.500 mm and a mean annual temperature of about 10°C. They occur over an elevation of between 1.500 and 1.650 m, on slopes that range from moderately steep to steep.

A typical profile shows:-

7	cm	coarse black scoriaceous sand and small basalt stones,
3	cm	gray scoriaceous sand and fine gravel,
15	cm	very dusky red coarse loamy sand,
10	cm	dark reddish brown loamy coarse sand,
On..		typical Chanleufu profile.

These soils are within the National Park and are thus protected from exploitation. Even under the natural forest, they appear to be rather highly erodable.

2. Intergrades to Red Volcanic Clays

The Red Volcanic Clays ('Suelos Rojos Arcillosos') of Chile form a large and agriculturally important group of soils in the National soil assemblage. Many of them are originally derived from volcanic ash, but with the passage of time the allophane present in their composition has evolved further into structured clays such as halloysite, metahalloysite, kaolinite and gibbsite. The evolution of the clay fraction in these soils is accompanied by very distinctive changes in colour, texture, and consistence which makes it comparatively easy to identify the stage of development of these volcanic ash soils in the field.

Usually, there is a fairly sharp distinction between the volcanic ash soils in the 'trumao' stage of development, and the more advanced soils with the characteristics of the 'rojos arcillosos'; the distinction is so sharp that there is some reason for thinking that the latter soils represent volcanic ash materials belonging to an inter-glacial epoch. This may be true of the majority of the red clay soils of the lowlands, but it is manifestly not true of the red clay materials that occur at depth below the trumao soil materials of the Andean ranges. Careful examination of the stratigraphic sequence in these latter soils shows that there is a gradual diminution of the typical trumao (allophane) characteristics in successive strata, and a corresponding gradual increase in the typical 'red clay' characteristics; the whole sequence representing a normal change with increasing a e of the materials. Since the distribution of ash shower materials varies greatly from one eruption to another, it is inevitable that situations occur where the mantle of younger ash is relatively thin, and the subsoil is formed from older materials in which typical trumao characteristics are no longer present. In such situations one finds that many of the soils are intergrades between trumao soils and red volcanic clays. In some cases the intergrade is clearly a case of an admixture of a shallow layer of trumao material in the red clay material, but in many cases an intermediate type of soil is formed which has some of the characteristics of a trumao, and some of the characteristics of the red volcanic clays. One example of each type of intergrade is given below.

i) Collipulli sandy loam (see Appendix, profile N° 62)

This soil is found near the limit of the Santa Barbara soils at about 6 km east of the town of Collipulli, at an elevation of about 260 m, on landscapes of gently rolling relief. The mean annual rainfall is 1.300 mm, and the mean annual temperature about 12.5°C. The original plant cover was probably forest, although none now remains in the region.

The soil profile shows:-

5	cm	dark brown sandy loam,
10	cm	dark reddish-brown sandy clay loam,
45	cm	dark reddish brown clay loam grading to clay,
80	cm	reddish brown compact clay
150	cm	dark brown heavy plastic clay
40	cm	dark reddish-gray heavy clay
On..		weathering andesitic breccia.

This soil is a valuable farming soil, but is highly erodable, even on gentle slopes. It is of moderate to low fertility, and is especially deficient in phosphate and lime.

ii) Maquehue loam (see Appendix, profile N° 63)

Maquehue soils are found on the rolling landscapes between Temuco and the coast in the Province of Cautin. They occur over an elevation of 80 to 180 m, and are developed under a climate with about 1.200 mm annual rainfall, and under mean annual temperatures of about 12°C. The original plant cover was Nothofagus obliqua forest.

A typical profile shows:-

10	cm	dark brown slightly sandy loam,
35	cm	brown heavy sandy loam,
45	cm	dark yellowish brown sandy clay loam,
20	cm	yellowish brown heavy sandy clay loam,
On..		yellowish brown to brown clay loam.

Maquehue soils are mainly used for wheat growing by the Araucanian Indian farmers of the region, but yields are generally low owing to the very low availability of phosphate in these soils.

1) Intergrades between Ñadi soils and other soil groups

1. Intergrades to Humic Gley soils

General features

Near the northern limit of the Ñadi soils, there are some soils which show characteristics intermediate between Ñadi soils and Humic Gleys. Typically these soils are much less gleyed in the subsoil than Humic Gleys, but in place of the gleyed horizon they have a rather bright yellowish horizon. They are developed from alluvial materials containing a high proportion of volcanic ash minerals, usually emplaced over old river terrace gravels. There is no sign of the development of an iron pan, such as occurs in some true Ñadi soils.

i) Freire silty clay loam (see Appendix, profile N° 64)

Freire soils are developed on flattish terrace landscapes, at an elevation of about 100 m, and under a climate with about 1.100 mm rainfall per annum and mean annual temperatures of about 12°C. The original plant cover was a semi-swamp forest.

A typical profile shows:-

35 cm very dark gray silty clay loam,
20 cm dark brown, very slightly mottled dark gray and yellowish brown clay loam,
25 cm strong brown to brownish yellow, rather plastic clay,
10 cm brown gravelly clay
On.. compact gravels and clay

Freire soils are very valuable farming soils, both for pastureland and occasional cropping. They repond well to topdressing with phosphate.

2. Intergrades to Podsolic Gleys and Gley Podzols

General features

Intergrades of this type are particularly common in Chiloe Island. They are generally shallow soils formed, in the upper part of the profile from volcanic ash materials, and in the lower part from the underlying rock which is usually mica schist or quartz gravel beds. These soils are developed mainly on landscapes of gentle relief, occasionally in lowland situations, but more commonly on upland plateau, in localities with relatively high annual precipitation (ranging from 2.000 mm to over 3.000 mm) and quite low annual temperatures (mean annual temperature about 10°C to 8.5°C). The natural plant cover on these soils was, in most cases, forest, ranging from Nothofagus dombeyi and N. antarctica, to Fitzroya and Saxegothea. Characteristically, there is a thick layer of raw forest humus formed on the surface of the soil. In some places, tal tussock vegetation replaces the natural forest vegetation, but this plant association may be the result of burning and grazing.

i) Maldonado peaty sandy loam (see Appendix, profile N° 65)

Maldonado soils are developed on the upland plateau of the coastal range in Chiloe Island, at an altitude of about 900 m, under a climate that is almost continuously wet and cool (mean annual rainfall about 4000 mm, and mean annual temperature about 9°C). These soils are at present under a tussock grassland cover with scattered plants of Saxegothea. The underlying rock is mica schist, thickly seamed with veins of quartz.

A typical soil profile shows:-

5 cm dark brown peaty sandy loam,
25 cm gray brown siltloam, mottled dark reddish brown along the root channels, and pale gray,
10 cm greenish gray gravelly sandy loam with many fragments of quartz and weathering micaschist,
On.. soft, laminar fragments of micaschist, quartz fragments and a little pale gray sandy loam.

Maldonado soils are used for occasional grazing with sheep and cattle, but they are of low natural fertility and the grazing regime is mantained only by repeated burning of the tussock during the summer months. In areas where the natural forest is largely undisturbed, the soils have from 15 to 35 cm of raw forest humus peat on the surface; over the burned areas, peat bog formation is developing strongly on all the flattish and concave areas.

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A considerable amount of the data presented in this report represents material gathered over the past 17 years by the Chilean soil survey group, and all the laboratory data is the work of Chilean (and a few New Zealand) soil chemists. Helpful advice was also received from Dr. Kanno of Japan. This combined contribution by Chile, Japan and New Zealand is no accident: these are the three major countries that have common volcanic ash soil problems, and it is of the outmost importance that, in future investigations of volcanic ash soil problems, this co-operation between these three countries should be mantained and strengthened.

In carrying out my own small part of the investigation, - which was mainly that of a field correlator - I have been very greatly helped by the willing co-operation of all the Chilean soil surveyors and chemists, both those employed by the Chilean Government in the Ministry of Agriculture, by those of the Universities, and by those operating in a private sphere. Amongst the latter, Dr. Elías Letelier should have special mention for he is one of the foremost scientists in the field of soil-plant relationships in Latin America, and is ever-ready with help and advice. Sr. Carlos Diaz Vial and Sr. Mario Peralta of the Ministry of Agriculture have also been most willing collaborators. To these gentlemen, and to the rest of the Chilean soil survey group, I tender my sincere thanks : it has been a pleasure to be associated with them.

APPENDIX

PROFILE DESCRIPTIONS OF SOILS MENTIONED IN THE TEXT

List of soils described

Profile No.1 - Poroma sand

Location : near Central station on Arica - La Paz railroad, Tarapacá Province.
Altitude : 1450 m.
Relief : undulating.
Parent material: rhyolitic pumiceous volcanic ash.
Plant cover : completely barren of vegetation.

Profile

7 cm pinkish-gray (5YR 7/2, dry) very hard and cemented pumice; relatively smooth surface above, but honeycombed below and the spaces are occupied by chalky material, probably mirabillite,

11 cm whitish cemented pumice; massive structure but with prominent vertical fissures occupied by softer, pumice with a vertically laminated structure,

27 cm very soft whitish (7.5YR 8/1) gravelly very fine sand,

on.. salt-impregnated, locally cemented pumice; with pockets of soft pumice in somewhat honeycombed structure; various layers of hard, massive, gypsum-cemented pumice.

Profile No. 2 - Campanani coarse sand

Location : about 8 km southwest of Sapahuira, Tarapacá Province.
Altitude : 3150 m.
Relief : flattish surface of small mesa.
Parent material: rhyolitic pumiceous volcanic ash.
Plant cover : almost barren; occasional scattered Baccharis tola plants.

Profile

0 - 2 cm	very pale brown (10YR 7/4, dry; dark brown, 7.5YR 3/2, moist) very slightly loamy coarse sand; weakly developed laminar structure; non-sticky and non-plastic when moist; boundary distinct,
2 - 9 cm	reddish-brown (5YR 5/4, dry) coarse loamy sand with fragments of decomposing rhyolitic rock; fairly firm when dry, friable when moist; weakly developed medium blocky structure; very slightly calcareous; non-sticky and very slightly plastic when moist; boundary merging,
9 - 18 cm	yellowish red coarse sandy loam; fragipan when dry, fairly friable when moist; somewhat varicoloured owing to iron-staining on some of the pumice and rhyolite fragments; breaks under pressure into fine angular blocks, also faintly stained light red on surfaces; non-sticky and almost non-plastic when moistened; boundary distinct,
18 - 22 cm	pinkish-white rather compact and weakly cemented coarse pumice sand and gravel; possibly slightly cemented by silica; boundary diffuse,
on..	whitish pumice gravel, fairly compact in place but quite loose when disturbed.

Profile No. 3 - Ocsaya sand

Location : about 8 km west of Ticnamar township, Tarapacá Province.
Altitude : 3300 m.
Relief : very slightly undulating.
Parent material: mainly rhyolitic volcanic ash with some sheet wash.
Plant cover : sparse 'tantalagua' bushes.

Profile

2 cm dark brown (7.5YR 3/2, moist, very pale brown - 10YR 7/4 - dry) sand; in places this sand drift is very slightly crusted on the surface with salt crystals and shows some laminar layering below; non-sticky and non-plastic when moist, boundary sharp; (pH 6.6); the top centimeter of the soil contains fragments of organic residues from the vegetation,

5 cm varicoloured slightly gravelly coarse loamy sand; colours are 'blotchy' due to uneven weathering within the horizon, possibly related to the former portion of plant roots; basic colour brown (7.5YR 4/4) when moist, with patches reddish-brown (5YR 4/4) [dry: 7.5YR 6/4, light brown and 5YR 5/4, reddish brown] with tendency for reddish colours to be stronger in the vertical fissure pattern and than in the horizontal laminar, pattern; reddish coloured patches tend to have more clay; whole horizon is friable when moist, but tends to have fragipan crispness when dry; no consistent aggregation, and virtually a structureless horizon; very slightly sticky and slightly plastic when moist; boundary distinct; (pH 7.0, no effervescence with HCl, local digestion and effervescence with H_2O_2),

6 cm slightly gravelly sandy clay loam (pumice gravel) of general brown colour (7.5YR 4/4, moist; 7.5YR 7/3, pale brown when dry), but faint areas of more reddish colour are also visible; very friable when moist but distinct weak cementation when dry, i.e. with fragipan characteristics; massive structure but breaks into flattened laminar aggregates of size of coarse granules under pressure when dry; very slightly sticky and slight to moderately plastic when moist; boundary diffuse; (pH 7.2; no effervescence with HCl; slight effervescence and digestion with H_2O_2),

20 cm stratified layers of sandy clay loam and loamy coarse sand, both mixed with fine pumice gravel; heavier textured layers are from 3 cm to 5 cm in thickness, and are distinctly cemented (probably with silica) forming hard, brittle fragipans pans interlayered with loose loamy coarse sand completely lacking cementing material; colour of cemented layers is 5YR 4/6, (yellowish red) when moist, (7.5YR 6/4, dry), finely mottled 5YR 7/3 and 5YR 7/4; colour of non-cemented layer is also 5YR 4/6 when moist (5YR 6/4, light reddish brown, dry) but without mottles; roots of present vegetation tend to spread laterally between cemented layers and extend to a depth of ± 35 cm below surface; no consistent form of structural aggregates; non-sticky and very slightly plastic when moist; boundary sharp; (pH 6.8 in non-cemented layers, 7.7 in cemented layers; weak to moderate effervescence and digestion with H_2O_2).

on.. soft powdery pumice sand and silty sand; very tightly packed but not cemented; hard when dry, friable when moist; massive; non-sticky and non-plastic when moist; colour light brown (7.5YR 6/4) and pink (7.5YR 5/4) dry; (pH 7.8 and moderate effervescence with HCl).

Profile No. 4 - Chubire sand

Location : at Parinacota-Cauquena-Allane cross-road junction on Chilean Altiplano, Tarapacá Province.
Altitude : 4600 m.
Relief : very gently undulating.
Parent material: rhyolitic pumiceous volcanic ash.
Vegetation : Stipa ichu grassland and Baccharis tola scrub.

Profile

0.5 cm dry litter of twigs and leaves of tola (pH 6.4),

1.5 cm gray sand (10YR 5/1) sand with very small pumice stones; friable, non-sticky and non-plastic when moist; single grain structure; boundary sharp; (pH 6.6; moderate reaction with H_2O_2, no reaction with HCl),

20.0 cm very pale brown (10YR 7/4) loamy coarse sand; friable-to-firm (suggestion of a fragipan - very weak cementation); contains pumice stones up to 1 cm diameter; structureless; non-sticky and non-plastic when moist; boundary indistinct; (pH 6.7; no reaction to H_2O_2 or HCl),

50.0 cm similar to last horizon but pumice stones are softer and more weathered; colour of soil 10YR 7/4 - 7.5YR 7/4 - i.e., slightly pinkish pale brown,

on.. compact weathered coarse pumice.

Profile No. 5 - San Martín sand

Location	:	saddle between Salar San Martín and Salar Ascotán, about 20 km southwest of Ollagüe, Antofagasta Province.
Altitude	:	3800 m.
Relief	:	undulating.
Parent material	:	mixed andesitic and rhyolitic volcanic ash.
Plant cover	:	Baccharis tola scrub, and occasional Stipa tussocks.

Profile

0 - 2 cm	pale brown (10YR 6/3, dry) fine sand and a little silt; very friable; fairly compact in place but with weakly developed laminar structure and weak development of short vertical fissures; breaks into rather square medium blocks; non-sticky and non-plastic when moist; boundary distinct,
2 - 10 cm	brown (7.5YR 5/4, dry) gravelly loamy sand; very friable to loose; very fine subangular blocky structure breaking to granules; fine white threads of calcium carbonate near root channels; non-sticky and non-plastic when moist; boundary distinct,
10 - 16 cm	pink (7.5YR 7/4, dry) coarse loamy sand with much pumice gravel; firm in place but crumbles readily when displaced; no regular structure; non-sticky and non-plastic when moist; boundary merging,
16 - 36 cm	pinkish-white (7.5YR 8/2, dry) pumice gravel (andesitic); rather compact and perhaps weakly cemented in place; breaks to single lumps of pumice and loose sand; non-sticky and non-plastic when moist; boundary distinct,
36 - 45 cm	dark gray (7.5YR 4/0, dry) black basaltic sand; cemented; slightly fissured and cracks stained reddish yellow; boundary abrupt,
45 - 50 cm	pale yellow (2.5YR 7/4, dry) coarse pumiceous sand; weakly cemented,
on..	moderately cemented pumiceous gravels alternating with dark brown basaltic sand.

Profile No. 6 - Lascar gravelly sand

Location : 5 km west of Lascar volcano, Antofagasta Province.
Altitude : about 3000 m.
Relief : strongly rolling.
Parent material: mainly pumiceous volcanic ash.
Plant cover : sparse cover of Baccharis tola with small cacti.

Profile

0 - 15 cm	reddish-gray (5YR 5/2, dry; dark brown, 7.5YR 3/2, moist) gravelly sand; without structure; non-sticky and non-plastic when moist; boundary diffuse,
15 - 30 cm	brown (7.5YR 5/4, dry; reddish brown, 5YR 3/3, moist) sand; grading to coarse loamy sand towards lower part of this horizon; very friable; somewhat compact in place and without recognisable structure, but breaks under gentle pressure to irregular sub-angular blocks and granules; non-sticky and non-plastic when moist; boundary diffuse,
30 - 45 cm	reddish brown (5YR 5/4, dry; dark reddish brown, 5YR 3/4, moist) slightly gravelly loamy sand; weakly developed medium and fine subangular blocky structure, which breaks further to granules and crumbs; non-sticky and very slightly plastic when moist; boundary sbrupt,
on..	hard rhyolitic lava sheet with fissures containing yellowish brown silty clay loam with pronounced 'greasy' feel when moist.

Profile No. 7 - Piedra Solitaria fine sand

Location	:	2 km west of Argentinian border, near Coyhaique Alto, Aysén Province.
Altitude	:	700 m.
Relief	:	rolling.
Parent material	:	probably mainly subaerial volcanic ash, in part pumiceous, mixed with volcanic loess.
Plant cover	:	Festuca tussock grassland.

Profile

0 - 15 cm	light brownish gray (10YR 6/2, dry; dark brown, 10YR 3/2, moist) fine sand; very friable, powdery when dry; no structure; non-sticky and non-plastic when moist; boundary distinct,
15 - 40 cm	dark grayish brown (10YR 4/2, dry; dark brown, 7.5YR 2/2 - 10YR 4/3, moist) slightly loamy sand; very friable, somewhat powdery when dry; extremely weak blocky structure, easily powdered to single grains; non-sticky and non-plastic when moist; boundary merging,
40 - 60 cm	light yellowish brown (10YR 6/4, dry; yellowish brown, 10YR 5/6, moist) rather coarse sand with fine pumice fragments; friable, but slightly compact in place; easily broken into irregular weakly developed blocks and granular aggregates; non-sticky and non-plastic when moist,
on..	darker yellowish brown stony sandy clay.

Profile No. 8 - Sora very fine sandy loam

Location : 55 km east of Chacabuco, Lluta Valley, Tarapacá Province.
Altitude : about 1000 m.
Relief : steep, loess-covered lower valley sides.
Parent material: fine loessic dust from river bed.
Plant cover : barren.

Profile

0 - 5 cm — pale brown (10YR 6/3) dry, or dark yellowish-brown (10YR 4/4) moist, very fine sandy loam; loose or very friable; non-sticky but very slightly plastic when moistened; almost structureless, slight tendency for very weak fine blocky aggregation; pH 4.9; non-calcareous; very slight reaction with hydrogen peroxide; boundary diffuse,

5 - 15 cm — light yellowish-brown (10YR 6/4) dry, or strong brown (7.5YR 5/4) moist, very fine loamy sand mixed with some fine angular liparitic gravel; friable to loose; non-sticky and non-plastic when moistened; very weakly developed irregular medium blocky structure breaking to crumbs and single grains under very slight pressure; pH 6.8; non-calcareous; no reaction to hydrogen peroxide; boundary distinct,

on.. — light brownish-gray (10YR 6/2) dry, or dark grayish-brown (10YR 4/2) moist, gravelly sand with angular rock fragments; salt-impregnated and slightly cemented; non-sticky and non-plastic when moist; weak laminar structure in gravel; pH 7.5; no reaction to hydrogen peroxide; boundary not seen.

Profile No. 9 - Alhue sandy loam

Location :	about 3 km south of Los Quillayes, O'Higgins Province.
Altitude :	130 metres.
Relief :	strongly rolling.
Parent material:	siliceous pumiceous rhyolitic volcanic ash.
Plant cover :	Quillay forest with litre, boldo, etc.

Profile

0 - 15 cm	dark brown (10YR 3/3, moist) sandy loam; rather firm in place but breaking with difficulty when displaced when slightly dry, friable when thoroughly moist, very hard when very dry; moderately developed medium subangular blocky structure breaking to fine blocks and granules; non-sticky and non-plastic when moist; boundary distinct, (field pH 5.8),
15 - 30 cm	brown to dark brown (10YR 4/3, moist) fine sandy loam; friable when throughly wetted, but somewhat hard when dry; moderately developed medium and fine subangular blocky structure, breaking to very fine granules and crumbs; occasional fine moderately hard concretions of manganese-humus compounds; non-sticky and non-plastic when moist; boundary abrupt, (field pH 6.3),
30 - 33 cm	dark brown (10YR 4/3 - 3/3, moist) very strongly cemented hard pan consisting offine pumiceous sand cemented with silica, not soluble in either cold or hot water, lower limit abrupt, (field pH 6.3),
33 - 48 cm	dark yellowish brown (10YR 4/4, moist) fine pumiceous sand with occasional small pumice stones; very friable to loose; no recognisable structure in the mass but breaks readily to very weakly developed very fine angular blocks, and further to separate sand grains; non-sticky and non-plastic when moist; boundary diffuse, (field pH 6.8),
on..	very pale brown (10YR 7/3, moist) fine pumiceous sand; loose and powdery; no visible structure in the mass or when extracted from profile; non-sticky and non-plastic when moist; continues to more than 1 metre, (field pH 7.6).

Profile No. 10 - Loreto peaty loamy sand

Location : about 10 km southwest of Punta Arenas city on road to Ski Club, Magallanes Province.
Altitude : about 320 metres.
Relief : strongly undulating uplands.
Parent material: terminal moraine materials of 4th glaciation with light covering of siliceous volcanic ash.
Plant cover : Magallanes deciduous forest with ñirre and lenga.

Profile

0 - 5 cm very dark brown (10YR 3/2, moist) slightly sandy loamy peat; slightly fibrous and with distinct laminar structure; boundary abrupt, (pH 4.9),

5 - 19 cm gray to pale gray (10YR 6/1, moist) slightly peat-stained fine sandy loam; rather firm, hard when dry; coarse laminar structure formed of horizontally flattened angular aggregates of medium to fine size; slightly sticky and very slightly plastic when moist; boundary abrupt and wavy, (pH 4.6),

19 - 25 cm dark reddish brown to reddish brown (5YR 3/3 - 4/3, moist) very fine sandy clay loam to silty clay loam; friable-to-firm when moist, slightly hard when dry; moderately developed medium blocky structure breaking readily to granules; aggregates slightly and irregularly coated with clayskins, with organic matter and with some iron oxide accumulation; aggregates slightly crisp; moderately sticky and slightly plastic when moist; boundary diffuse, (pH 5.0),

25 - 40 cm reddish brown (5YR 4/3, moist) heavy sandy loam; compact in nature; very hard when dry; appears to have a very strongly developed laminar structure probably inherited from the glacial parent materials; slightly sticky and slightly plastic when pulverised and moistened; boundary indistinct, (pH 5.2),

on.. reddish brown (5YR 4/3, moist) sandy loam to loamy sand; somewhat compact but less so than last horizon; strongly marked glacial-compression horizontal striations, with some accumulation of iron in the cracks; grading into very gravelly and stony glacial materials.

Profile No. 11 - Hornillos fine sandy loam

Location	:	2.5 km west of entrance of Hornillos irrigation tunnel, Linares Province.
Altitude	:	735 metres.
Relief	:	undulating terrace, somewhat dissected and eroded.
Parent material	:	volcanic ash and volcanic loess, andesitic.
Plant cover	:	secondary forest with 'roble maulino', radal, canelo.

Profile

0 - 15 cm	dark brown (7.5YR 3/2, dry; 5YR 3/4, dark reddish brown, moist) fine sandy loam; very friable; breaks readily to very fine granules and crumbs; non-sticky and non-plastic when moist; boundary diffuse,
15 - 35 cm	reddish brown (5YR 4/4, dry; dark reddish brown, 5YR 3/4, moist) sandy loam; friable-to-firm; weakly developed coarse and medium subangular blocky structure, breaking easily to crumbs and very fine granules; non-sticky and non-plastic when moist; boundary distinct,
35 - 60 cm	brown (7.5YR 4/4, dry and moist) silty clay loam to very light clay loam; firm-to-friable; moderately well developed coarse angular blocky structure, almost weakly prismatic, breaking fairly easily to very fine blocks and coarse granules; very slightly sticky and slightly plastic when moist; boundary diffuse,
60 - 140 cm	mainly strong brown (7.5YR 5/6, dry; dark yellowish brown, 10YR 4/4, moist) with patches of weak red (10YR 4/3, dry; yellowish red, 5YR 5/6, moist) caused by included fragments of andesitic rock, silty clay loam; firm, hard when dry; very strongly developed very coarse blocky structure, breaking with difficulty to irregular medium and fine blocks; very slightly sticky and slightly plastic when wet; boundary merging,
on..	weathering andesitic rock.

Profile No. 12 - Maitén very fine sandy to silt loam

Location : 22 km east of San Clemente, Talca Province
Altitude : about 600 metres.
Relief : undulating to rolling.
Parent material: volcanic loess, mixed andesitic and rhyolitic.
Plant cover : maitén, boldo, litre, 'róble maulino', maquis, etc.

Profile

0 - 30 cm	brown to dark reddish gray (7.5 - 5YR 4/2, dry; very dark brown, 10YR 2/2, moist) very fine sandy loam to silt loam; very friable; very weakly developed fine blocky structure, breaking easily to fine granules and crumbs; very slightly sticky but non-plastic when moist; boundary distinct,
30 - 70 cm	yellowish brown (10YR 5/4, dry; dark yellowish brown to dark brown, 10YR - 7.5YR 4/4, moist) silt loam; friable-to-firm; weakly developed coarse blocky structure breaking to medium and fine blocks, and further to coarse granules; practically non-sticky but very slightly plastic when moist; boundary distinct,
70 - 150 cm	dark yellowish brown (10YR 4/4, dry; dark brown to dark reddish brown, 7.5YR 4/4 - 5YR 3/2, moist) heavy very fine sandy loam with occasional small stones; firm-to-friable; no visible structure in place but breaks to weakly developed irregular blocks of coarse size, and further to fine angular blocks and granules; slightly sticky and moderately plastic when moist; boundary distinct,
on..	dark yellowish brown fine sandy clay loam with occasional layers of fine stones, stream-bedded; grading with increasing depth to old river gravels.

Profile No. 13 - Tregualemu very fine sandy loam

Location	:	10.4 km east of Cobquecura, Maule Province.
Altitude	:	375 metres.
Relief	:	undulating.
Parent material	:	probably mainly volcanic loess.
Plant cover	:	forest with boldo, litre, arrayán, maitén, etc.

Profile

0 - 15	brown (10YR 4/3, dry; very dark grayish brown, 10YR 3/2, moist) very fine sandy loam; friable; breaking on separation from the mass into very fine blocks, granules and crumbs; non-sticky and very slightly plastic when moist; boundary distinct,
15 - 80 cm	light yellowish brown (10YR 6/4, dry; dark brown to dark reddish brown, 7.5YR 3/2 - 5YR 3/3, moist) silty clay loam to loam; very friable, somewhat powdery when dry; very weakly developed medium blocky structure, breaking to very fine blocks, granules and crumbs; very slightly sticky and slightly plastic when moist; boundary diffuse,
80 - 100 cm	dark yellowish brown (10YR 4/4, dry; dark reddish brown to brown, 5YR 3/4 - 7.5YR 4/4, moist) silty clay loam; friable-to-firm; almost without defined structure in place but breaking under slight leverage to very weakly developed irregular blocks of all sizes, and these break further to granules and crumbs; moderately sticky and moderately plastic when moist; boundary abrupt,
on..	compact, mottled clayey beds with a pronounced stone layer along contact; red, white and yellowish brown sandy clay lies below the stone line; grading to weathered shaley beds at about 170 cm.

Profile No. 14 - Ñirreguao slightly loamy sand

Location : about 10 km west of Coyhaique Alto on road to Coyhaique, Aysén Province.
Altitude : about 600 metres.
Relief : gently rolling.
Parent material: mainly andesitic and rhyolitic volcanic ash.
Plant cover : ñirre forest of dwarf stature.

Profile

0 - 2.5 cm dry leaves and twigs derived from ñirre forest,

2.5 - 12 cm dark reddish brown to dark brown (7.5 - 5YR 3/2, moist) slightly loamy sand; very friable, powdery when dry; no recognisable structure; non-sticky and non-plastic when moist, boundary distinct,

12 - 22 cm dark brown to dark yellowish brown (10YR 3/4 - 7.5YR 4/4, moist) sand; very friable, powdery when dry; very weakly developed fine blocky structure powdering easily to single grain; non-sticky and non-plastic when moist; boundary merging,

22 - 50 cm yellowish-brown to brown (10YR 5/4 - 7.5YR 4/2, moist) coarse sand; very friable; no structure; non-sticky and non-plastic when moist; boundary diffuse,

on.. pale yellowish brown very coarse sand.

Profile No. 15 - Laguna del Maule loamy sand

Location : about 1 km northwest of Laguna del Maule, Talca Province.
Altitude : 2060 metres.
Relief : rolling to strongly rolling.
Parent material: pumiceous rhyolitic volcanic ash of mainly subaerial origin, mixed with some volcanic loess.
Plant cover : tussock grassland, in part Stipa, Festuca etc.

Profile

0 - 40 cm light brownish gray (10YR 6/2, dry; very dark gray brown, 10YR 3/2, moist) loamy sand; very friable; without structure in the mass but when carefully levered out from the mass, breaks into very weakly developed, regular medium blocky structure; non-sticky and non-plastic when moist; boundary distinct,

40 - 85 cm light reddish brown to reddish yellow (5YR 6/4 - 6/6, dry; reddish brown to yellowish red, 5YR 5/4 - 5/6, moist) heavy sandy loam; friable-to-firm; weakly developed irregular blocky structure, breaking to granules under pressure; slightly sticky and slight-to-moderately plastic when moist; boundary distinct,

on.. weathering pinkish andesitic (acid) rock.

Profile No. 16 - Santa Bárbara very fine sandy loam, Chillán facies

Location : 30 km southeast of Chillán, near Recinto, Ñuble Province.
Altitude : about 1000 metres.
Relief : flattish ridge in strongly rolling landscape.
Parent material: mainly subaerial andesitic ash mixed with loess.
Plant cover : roble forest, with canelo, olivillo, etc.

Profile

0 - 20 cm	dark brown (10YR 4/3, dry; very dark brown to dark reddish brown, 7.5YR 3/2 to 5YR 3/2, moist) very fine sandy loam; friable; weakly developed very fine subangular blocky structure, with an abundance of fine and very fine granules, and crumbs; many roots; non-sticky and very slightly plastic when moist; boundary distinct,
20 - 50 cm	dark yellowish brown grading to yellowish brown (10YR 4/4, and 10YR 5/4, dry; dark reddish brown to dark brown, 5YR 3/3 to 7.5YR 3/2, moist) very fine sandy loam to loam with fairly hard rounded nodules composed of aggregated soil material; very friable indeed, soft and powdery when dry; very porous; very fine granular and crumb structure; not easy to wet, but when moist is non-sticky and practically non-plastic; boundary diffuse,
50 - 90 cm	yellowish brown (10YR 5/4, dry; reddish brown, 5YR 5/4, moist) loam; friable-to-firm, slightly hard when dry; moderately well developed medium subangular blocky structure, breaking to coarse and fine granules; somewhat difficult to wet, but when moist shows no stickyness and very slight plasticity; very weak indications of clay flows on larger peds; boundary merging,
90 - 140 cm	yellowish brown (10YR 5/4, dry; dark brown to brown, 7.5YR 4/4, moist) silty clay loam; firm-to-friable, often rather hard when dry; moderately well developed coarse and medium subangular to angular blocky structure, with some weak indication of clay flows on surface of aggregates, breaking to fine blocks and coarse granules; non-sticky and slight-to-moderately plastic when moist; boundary distinct,
140 - 180 cm	pale yellowish brown (10YR 6/4, dry; strong brown, 7.5YR 5/6, moist) slightly gravelly sandy clay loam with decomposing lumps of pumice; firm and compact, hard when dry; no recognisable structure in the mass, breaks irregularly; slightly sticky and moderately plastic when moist; boundary sharp,
on..	various strata of andesitic ash and pumiceous rhyolitic ash continuing to a depth of over 4 metres.

Profile No. 17 - Santa Bárbara very fine sandy loam, Santa Bárbara facies

Location : 5 km northwest of Santa Bárbara township, Bío-Bío Province.
Altitude : about 480 metres.
Relief : rolling, strongly dissected in part.
Parent material: andesitic volcanic materials, mainly loessic.
Plant cover : secondary scrubland with romerillo, etc.

Profile

0 - 20 cm	dark brown (10YR 4/3, dry; dark brown to dark reddish brown, 7.5YR 3/2 - 5YR 2/2, moist) very fine sandy loam to silt loam; very friable; weakly developed fine subangular blocky and granular structure; very slightly sticky and plastic when moist; boundary distinct,
20 - 45 cm	brown (10YR 5/3, dry; very dark gray brown, 10YR 3/2, moist) silt loam; very friable indeed, soft and 'fluffy' when dry; strongly developed very fine blocky to fine granular structure; abundant rounded nodules formed of aggregated soil material, some baked into brick-like fragments and pinkish in colour; very difficult to wet, but when moist is non-sticky and only very slightly plastic, if at all; boundary diffuse,
45 - 125 cm	pale yellowish brown (10YR 6/4, dry; brown to strong brown, 7.5YR 4/4 - 5/6, moist) rather heavy silt loam; friable-to-firm, slightly hard when dry; weakly developed coarse blocky structure with slightly longer vertical axis (dries out in road banks to a very weakly developed prismatic structure), peds breaking under further pressure to fine blocks, granules and crumbs; very slight indications of clay flows; very slightly sticky and slight-to-moderately plastic when moist; boundary diffuse,
125 - 220 cm	strong brown to reddish yellow (7.5YR 5/6 - 6/6, dry, brown, 7.5YR 4/4, moist) silty clay loam; firm, hard when dry; very coarse, irregular prismatic-blocky structure, breaking further to medium angular blocks and coarse granules; very occasional clayskins on peds; slightly sticky and plastic when moist; boundary sharp,
on..	older volcanic ash materials, mainly yellowish brown, compact, clayey, and well structured.

Profile No. 18 - Santa Bárbara very fine sandy loam, Mulchén facies

Location : 34.5 km east of Mulchén, towards El Morro, Malleco Province.
Altitude : 535 metres.
Relief : very slightly undulating.
Parent material: andesitic volcanic ash, subaerial and loessic.
Plant cover : roble forest.

Profile

(surface litter of dry leaves and twigs about 3 cm in depth)

0 - 2 cm	dark brown (7.5YR 3/2, dry; very dusky red, 2.5YR 2/2, moist) slightly peaty very fine sandy loam; very friable; very fine crumb structure; non-sticky and non-plastic when moist; boundary distinct, (pH 6.0 [but patches of fungal mycelia have pH 5.0]),
2 - 22 cm	dark brown to dark reddish brown (7.5 - 5YR 3/2, dry; dark reddish brown, 5YR 2/2, moist) very fine sandy loam to loam; friable-to-firm when moist; very fine blocky and granular structure; very many roots; very hard to wet when dry, but non-sticky and very slightly plastic when moist; boundary diffuse, (pH 5.4),
22 - 32 cm	brown (7.5YR 4/4, dry; dark brown, 7.5YR 3/2, moist) loam; friable, loose and soft when dry; very weakly developed very fine subangular blocky structure, breaking to very fine granules; occasional rounded, very firm, very fine (one-eighth to one sixteenth cm diameter) nodules of soil; non-sticky and very slightly plastic when moist; boundary diffuse, (pH 5.6),
32 - 65 cm	brown (7.5YR 4/4, dry; dark brown to dark yellowish brown, 7.5YR 3/2 - 10YR 4/4, moist) loam to silty clay loam; very friable, very loose and 'fluffy' when dry; weakly developed blocky structure, but when dry in road banks shows irregular prismatic structures; ultimate peds in moist soil are no larger than crumbs; numerous hard nodules of soil, some up to 1/2 cm in diameter; very hard to wet if thoroughly dry; non-sticky but moderately plastic when thoroughly moistened; boundary diffuse,
65 - 130 cm	dark yellowish brown (about 7.5YR 5/6, dry; 10YR 4/4, moist) silty clay loam; friable-to-firm; very weakly developed blocky structure, barely discernable in the mass of moist soil (but road banks show very strong, if irregular, prismatic structures), breaking to granules; very slightly sticky and moderately plastic when moist; boundary distinct, (pH 5.8),
on..	stratified yellowish-brown ash shower layers and ash beds in part pumiceous, and in some cases compact and very hard when dry, (pH 6.0 - 6.4).

Profile No. 19 - Arrayán silt loam

Location	:	20 km southeast of Chillán, near Quiriquina, Ñuble Province.
Altitude	:	340 metres.
Relief	:	flattish to very gently undulating.
Parent material	:	volcanic alluvium over river gravels.
Plant cover	:	improved grassland (originally forest with roble but cleared and farmed about 150 years ago).

Profile

0 - 50 cm	dark gray (10YR 4/1, dry; black 10YR 2/1, moist) silt loam; friable-to-firm; moderately developed coarse irregular sub-angular blocky structure, breaking to coarse, irregular granules; non-sticky and very slightly plastic when moist; boundary distinct but somewaht disturbed by worm action; some pale yellowish worm-mottling at the base of this horizon,
50 - 140 cm	pale yellowish brown (10YR 6/4, dry; dark yellowish brown, 10YR 4/4, moist) fine sandy loam; friable; moderately well developed medium and fine blocky structure in moist soil, but in dry ditch sides a very strong vertical fissure pattern appears, resembling elongated prisms; very slightly sticky and moderately plastic when moist; boundary distinct,
140 - 180 cm	brownish yellow (10YR 6/6, dry; yellowish brown, 10YR 5/6, moist) sandy clay loam; firm; strongly developed coarse angular blocky structure, breaking to finer blocks and coarse granules; slightly sticky and moderately plastic when moist; boundary sharp,
on..	partially-cemented fine river gravel and clay.

Profile No. 20 - Baguales fine sandy loam

Location : Baguales Alto, about 7 km from Coyhaique, Aysén Province.
Altitude : about 300 metres.
Relief : gently rolling uplands.
Parent material: subaerial andesitic volcanic ash.
Plant cover : lenga forest, recently felled; in part sown in grass.

Profile

0 - 18 cm — dark brown (7.5YR 3/2, dry; dark reddish brown, 5YR 2/2, moist) fine sandy loam; friable; weakly developed medium granular structure, breaking easily to crumbs; non-sticky and very slightly plastic when moist; boundary distinct,

18 - 43 cm — brown (7.5YR 4/4, dry; dark brown, 7.5YR 3/2, moist) sandy loam; friable-to-firm; strongly developed coarse blocky structure, breaking to granules; non-sticky and very slightly plastic when moist; boundary merging,

43 - 75 cm — dark yellowish brown to brown (10YR - 7.5YR 4/4, dry; dark yellowish brown to yellowish red, 5YR 3/4 - 4/6, moist) heavy sandy loam; firm; weakly developed coarse blocky structure breaking to fine angular blocks and coarse granules; very slightly sticky and slightly plastic when moist; boundary distinct,

on.. — coarse gravelly sand with some clay; gravel is mainly pumiceous.

Profile No. 21 - Cautín silt loam, San Patricio facies

Location : 12 km north of Curacautín, road to Termas de Tolhuaca, Cautín Province.
Altitude : 585 metres.
Relief : rolling downland.
Parent material: andesitic volcanic ash, mainly subaerial.
Plant cover : roble forest

Profile

0 - 15 cm — dark grayish brown (10YR 4/2, dry; very dark brown, 10YR 2/2, moist) silt loam with very slight fine sandy feel; friable-to-firm; very strongly developed very fine angular blocky structure; very slightly sticky and slight-to-moderately plastic when moist; boundary diffuse,

15 - 30 cm — brown (10YR 4/3, dry; dark brown, 7.5YR 3/2, moist) silt loam; friable-to-firm; moderately developed medium and fine subangular blocky structure breaking very readily to fine granules and crumbs; fritters away easily in exposed road banks; slightly sticky and moderately plastic when moist; boundary distinct,

30 - 90 cm — brown to strong brown (7.5YR 4/4 - 5/6, dry; brown, 7.5YR 3/2, moist) silty clay loam; very friable, soft and loose when dry; rather structureless in the mass but breaks into weakly developed blocks of all sizes, also granules and crumbs; slight-to-moderately sticky and moderately plastic when moist; between 50 and 90 cm there is a discontinuous band of light yellowish coarse pumiceous material as if an old mud shower layer had been incorporated; boundary of main horizon distinct,

90 - 120 cm — yellowish brown (10YR 5/6, dry; dark yellowish brown, 10YR 4/4, moist) heavy silty clay loam to light clay loam; firm-to-friable, slightly hard if very dry; strongly developed coarse, regular blocky structure with longer vertical axes to individual aggregates, breaking to granules and some crumbs; has prominent shrinkage cracks in exposed road cuts when dry, giving appearance of irregular columnar, or coarse prismatic structure; moderately sticky and moderately-to-strongly plastic when moist; boundary distinct,

on.. — pale yellowish brown slightly sandy (pumiceous) clay loam, followed by other depositional strata, some silty and compact, some sandy and less compact.

Profile No. 22 - Cautín silt loam, Los Prados facies

Location : 'Los Prados' estate, about 55 km northeast of Temuco, Cautín Province.
Altitude : 525 metres.
Relief : very gently rolling.
Parent material: andesitic volcanic ahs, mainly subaerial.
Plant cover : secondary scrub, with michay, chacay, romerillo and some Festuca tussock grassland. Original roble forest felled 50 years ago, and land used occasionally for wheat; last wheat sown 5 years ago.

Profile

0 - 25 cm very dark gray (10YR 3/1, dry; black, 5YR 2/1, moist) silt loam; friable; very fine granular structure; non-sticky and non-plastic when moist; boundary distinct,

25 - 60 cm brown (7.5YR 4/4, dry; very dark brown to reddish brown, 7.5YR 3/2 - 5YR 4/4, moist) silt loam; firm-to-friable; strongly developed coarse blocky structure, breaking to medium and fine angular blocks, and breaking further to crisp coarse granules; all peds rather crisp; very slightly sticky but slight-to-moderately plastic when moist; occasional clayskins seen on larger aggregates; boundary diffuse,

60 - 80 cm brown to strong brown (7.5YR 5/4 - 5/6, dry; brown to dark yellowish brown, 7.5YR 3/2 - 10YR 4/4, moist) silty clay loam; rather firm; no recognisable structure in the mass, but breaks into weakly developed angular blocks, and these break further to very fine blocks, granules and crumbs; slightly sticky and moderately plastic when moist; boundary diffuse,

80 - 120 cm light brown (7.5YR 6/4, dry; strong brown, 7.5YR 5/6, moist) clay loam grading to sandy clay loam; firm-to-friable; no recognisable structure in the mass but can be readily broken to blocks of all sizes and granules; slightly sticky and plastic when moist; contains fragments of pumice in lower part; boundary distinct,

on.. stratified older ash beds and shower layers of general strong brown to dark yellowish brown colour.

Profile No. 23 - Cautín silt loam, Cumbli facies

Location : 43 km southeast of Temuco on road to Cunco, Cautín Province.
Altitude : about 480 metres.
Relief : gently rolling.
Parent material: andesitic volcanic ash, in part loessic.
Plant cover : roadside grasses, formerly roble forest.

Profile

0 - 15 cm	brown to dark brown (7.5YR 4/2 - 3/2, dry; dark reddish brown to dark brown, 5YR 3/4 - 7.5YR 3/2, moist); silt loam; firm-to-friable; weakly developed coarse subangular blocky structure breaking to fine granules and crumbs; non-sticky and non-plastic when moist, boundary distinct,
15 - 21 cm	brown (7.5YR 5/2, dry; reddish brown to brown, 5YR 4/4 to 7.5YR 4/4, moist) silt loam; very friable, loose when dry; very weakly developed irregular blocky structure, that crumbles almost at once to very fine granules and crumbs, except for some larger lumps that are quite firm and more resistant to pressure; non-sticky and very slightly plastic; boundary very diffuse and irregular,
21 - 95 cm	yellowish brown (10YR 5/4, dry; strong brown to brown, 7.5YR 5/6 - 4/4, moist) silty clay loam; firm, slightly hard when dry; strongly developed very coarse blocky structure with long vertical axes, breaking to coarse, medium, and fine blocks and granules; dry road banks show prominent vertical shrinkage cracks, giving appearance of irregular columns; small aggregates porous; larger aggregates with weak clayskins; slightly sticky and slight to moderately plastic when moist; boundary diffuse,
95 - 150 cm	similar to above but heavier silty clay loam, boundary distinct,
150 - 180 cm	strong brown to yellowish brown (7.5YR 5/6 - 10YR 4/4, moist) clay loam; firm; strongly developed medium and fine angular blocky structure with porous aggregates and surface clayskins; slightly sticky and moderately plastic when moist; boundary distinct,
180 - 390 cm	strong brown to yellowish red (7.5YR 5/6 - 5YR 4/6, moist) when cut with spade, but reddish brown (5YR 3/3, moist) on exposed face of road bank; silty clay; firm; slightly prismatic structure, breaking under strong pressure to medium and fine blocks and granules; many clayskins and pressure faces; peds very finely porous; slightly sticky and moderately plastic when moist; boundary diffuse,
on..	older ash beds, with marked stratification; general colour yellowish-red when moist; mainly silty clays, and well structured.

Profile No. 24 - Icalma loamy coarse sand

Location : about 0.5 km west of post office, Icalma settlement, Malleco Province.
Altitude : 1090 metres.
Relief : strongly rolling.
Parent material: rhyolitic pumiceous ash.
Plant cover : rough pasture, formerly Araucaria forest.

Profile

0 - 30 cm	black (10YR 2/1, moist) loamy coarse sand; firm-to-friable; weakly developed coarse blocky structure breaking to very fine granules and crumbs; non-sticky and very slightly plastic; boundary diffuse,
30 - 55 cm	dark brown (10YR 4/4, moist) loamy coarse sand; friable to very friable; strongly developed very fine granular and crumb structure; very slightly sticky and slightly plastic when moist; boundary merging,
55 - 80 cm	brown to dark yellowish brown (10YR 4/3 - 4/4, moist) coarse sandy loam with lumps of weathering pumice; very friable; very strongly developed fine granular structure; very slightly sticky and very slightly plastic when moist; boundary sharp,
80 - 170 cm	yellow (10YR 8/6, moist) pumice gravel; firmly packed; pumice lumps angular and ranging in size from 9 cm to less than 1 cm; some fine black gravel mixed with the pumice; boundary diffuse,
170 - 210 cm	very dark gray brown (10YR 3/2, moist) coarse sandy loam; friable-to-firm; no clearly distinguishable structure in the mass, but breaks to very fine granules and crumbs; slightly sticky and slightly plastic when moist; (most probably represents an old, buried topsoil horizon); boundary diffuse,
210 - 230 cm	dark grayish brown (10YR 4/2, moist) slightly gravelly sandy loam; firm-to-friable; no visible structure in the mass, but breaks to irregular fine blocks and granules; lumps of weathering pumice throughout this horizon; slightly sticky but only very slightly plastic when moist; boundary merging,
on..	strong brown (7.5YR 5/6, moist) gravelly sandy loam, with numerous pumiceous strata continuing below for over 5 m.

Profile No. 25 - Vilcún loam to silt loam

Location : Ministry of Agriculture Experimental Station "Santa Amalia", Vilcún, Cautín Province.
Altitude : about 180 metres.
Relief : flattish.
Parent material: volcanic alluvium.
Plant cover : remnant of original roble forest, with laurel, lingue and coigüe.

Profile

(surface layer of leafy mull, about 1.5 cm thick, very granular)

0 - 30 cm dark grayish brown (10YR 4/2, dry; very dark brown, 10YR 2/2, moist; dark brown, 10YR 3/4, crushed) loam to silt loam; friable-to-firm; very strongly developed very fine blocky and coarse granular structure; non-sticky, slightly plastic when moist; many worm casts on surface; boundary distinct,

30 - 60 cm brown (7.5YR 4/4, dry; dark brown to brown, 7.5YR 3/2 to 10YR 3/3, moist; dark brown to dark yellowish brown, 10YR 4/3 to 4/4, crushed moist) very fine sandy loam with occasional very fine rounded gravels; friable; very weakly developed medium and fine blocky structure, breaking to very fine granules and crumbs; very slightly sticky and slightly plastic when moist; boundary diffuse,

60 - 90 cm yellowish brown (10YR 5/4, dry; dark yellowish brown, 10YR 4/4, moist; strong brown, 7.5YR 5/6, crushed moist) fine sandy loam with more common small rounded stones; very friable; no visible structure in the mass but breaks to fine granules and crumbs; non-sticky and very slightly plastic when moist; boundary distinct,

90 - 120 cm yellowish brown (10YR 5/6, dry; dark yellowish brown to yellowish brown, 10YR 4/4 - 5/4, moist) loamy sand with abundant fine gravel and some larger stones; firm and rather compact, perhaps lightly cemented with iron oxides; no visible structure in the mass, breaks irregularly; slightly sticky, slight-to-moderately plastic when moist; boundary merging,

on.. less compact gravelly loamy sand of similar colour to last horizon, firm, and without visible structure in the mass.

Profile No. 26 - Temuco silt loam, deep phase

Location : 26 km south of Temuco, near Pitrufquén, Cautín Province.
Altitude : about 110 metres.
Relief : flattish.
Parent material: volcanic alluvium, mixed with volcanic loess.
Plant cover : roadside grasses, formerly roble and lingue forest.

Profile

0 - 15 cm	dark grayish brown to brown (10YR 4/2 - 4/3, dry; dark brown, 10YR 3/3, moist) silt loam; slightly firm when moist, slightly hard when dry; moderately developed fine subangular blocky structure; slightly sticky and slightly plastic when moist; boundary distinct,
15 - 30 cm	brown (10YR 4/3, dry; dark yellowish brown, 10YR 4/4, moist) silt loam; very friable, soft and somewhat loose when dry; weakly developed medium subangular blocky structure breaking easily to very fine granules; slightly sticky and slightly plastic when moist; boundary diffuse,
30 - 50 cm	dark yellowish brown (10YR 4/4, moist) silt loam; loose and friable when moist, soft when dry; many round insect chambers ('peloteros') in this horizon; very weakly developed medium subangular blocky structure breaking to fine blocks and granules; slightly sticky and slightly plastic when moist; boundary diffuse,
50 - 70 cm	yellowish brown (10YR 5/6, dry; dark yellowish brown, 10YR 4/6, moist) silt loam to heavy silt loam; very friable, soft and 'fluffy' when dry; irregular very fine granular and crumb structure; slightly sticky and slightly plastic when moist; boundary distinct,
70 - 170 cm.	slightly cemented medium sand with lines of rounded gravel, some of latter are coated with manganese and iron, boundary distinct,
on..	grayish to olive brown semi-cemented gravels and sand.

Profile No. 27 - Trevolhue very fine sandy loam

Location	:	approximately 17 km from Carrahue on road to Colonia Matte y Sánchez, Cautín Province.
Altitude	:	about 250 metres.
Relief	:	gently rolling.
Parent material	:	volcanic loess blown from adjacent river bed, mixed with local micaceous loess from schist hills.
Plant cover	:	roadside grasses, formerly roble forest.

Profile

0 - 20 cm	dark brown (10YR 4/3 - 2/2, dry; dark brown, 7.5YR 3/2, moist) very fine sandy loam; friable; strongly developed fine sub-angular blocky structure, breaking to fine granules and crumbs; non-sticky and very slightly plastic when moist; boundary diffuse,
20 - 45 cm	yellowish brown (10YR 5/4, dry; dark yellowish brown, 10YR 4/4, moist) heavy silt loam; friable; very weakly developed blocky structure breaking irregularly to fine angular blocks, granules, etc.; slightly sticky and moderately plastic when moist; boundary merging,
45 - 70 cm	yellowish brown (10YR 5/6, dry; dark yellowish brown to brown, 10YR 4/4 - 4/3, moist) silty clay loam; very friable; moderately developed coarse blocky structure with decided prismatic appearance, breaking to crumbs very readily; dry road banks show strong vertical shrinkage cracks resembling irregular columns; slight-to-moderately sticky and slight-to-moderately plastic when thoroughly moist; boundary abrupt,
on..	dark reddish brown (2.5YR 2/4, moist) silty clay of the much older volcanic ash beds in which kaolinitic clays are dominant; very strong prismatic structures; very strongly plastic

Profile No. 28 - Puerto Octay silt loam

Location : Centinela Experimental Station of Ministry of Agriculture, Puerto Octay, Osorno Province.
Altitude : about 200 metres.
Relief : almost level.
Parent material: andesitic volcanic ash, mainly subaerial.
Plant cover : roble forest with laurel, quila, etc.

Profile

0 - 13 cm very dark brown (10YR 2/2, dry; black, 10YR 2/1, moist) silt loam; friable; moderately developed fine and very fine granular structure; non-sticky and very slightly plastic when moist; boundary diffuse, (pH 6.4),

13 - 33 cm very dark grayish brown (10YR 3/2, dry; dark brown, 10YR 2/2, moist) silt loam; friable, soft when dry; moderately developed medium and fine subangular blocky structure; very slightly sticky and slightly plastic when moist; boundary diffuse, (pH 6.3),

33 - 59 cm brown (10YR 4/3, dry; dark brown, 10YR 3/3, moist) silt loam; friable, soft when dry; strong medium subangular blocky structure, breaking to coarse granules; slightly sticky and slightly plastic when moist; boundary distinct, (pH 6.0),

59 - 100 cm yellowish brown (10YR 5/4, dry; dark brown, 7.5YR 3/4, moist) silt loam; moderately developed fine and very fine subangular blocky structure; friable-to-firm; slightly sticky and slightly plastic when moist; boundary diffuse, (pH 5.8),

100 - 128 cm dark yellowish brown (10YR 4/4, dry; dark brown, 10YR 3/4, moist) silt loam; firm-to-friable; weakly developed fine blocky structure, breaking to very fine granules; slightly sticky and moderately plastic when moist; boundary distinct, (pH 5.8),

on.. brown (10YR 5/3, dry; dark brown, 10YR 3/4, moist) clay loam, somewhat compact in upper part, and perhaps weakly cemented with iron and silica; occasional basaltic gravels mixed through material; firm; no recognisable structure in the mass; slightly sticky and moderately plastic when moist; occasional manganese precipitation on gravel.

Profile No. 29 - Puerto Octay fine sandy loam

Location	:	1.5 km northwest of Puerto Varas on Pan-American Highway, Llanquihue Province.
Altitude	:	140 metres.
Relief	:	gently rolling.
Parent material	:	mixed andesitic and rhyolitic volcanic ash.
Plant cover	:	roadside grasses, formerly forest.

Profile

0 - 15 cm	very dark brown (10YR 2/2, moist) fine sandy loam; friable; very strongly developed fine subangular blocky structure, breaking to very fine blocks and coarse granules; non-sticky and very slightly plastic when moist; boundary distinct,
15 - 40 cm	brown to strong brown (10YR 5/4 - 5/2, moist) sandy loam; friable; rather massive (i.e. no visible structure) but breaks to coarse granules; very slightly sticky and very slightly plastic when moist; boundary diffuse,
40 - 60 cm	strong brown to yellowish-red (7.5YR 5/6 - 5YR 5/6, moist) silt loam; very friable, soft and loose when dry; weakly developed coarse blocky structure breaking to granules and crumbs; some development of vertical shrinkage cracks in roadside banks; very slightly sticky; slight-to-moderately plastic when moist; occasional lumps of firm brownish-yellow sandy loam at lower limit of this horizon; boundary distinct,
60 - 120 cm	brown (10YR 4/3, moist) slightly sandy clay loam; firm to very firm, rather hard when dry; strongly developed coarse blocky structure breaking to irregular fine and medium blocks; occasional grayish patches of sandy clay included in this horizon, as if the material contains the remnants of an old mud-shower; very slightly sticky, moderately plastic when moist; boundary distinct,
120 - 140 cm	strong brown to brownish yellow (10YR 5/8 - 6/8, moist) clay loam to clay; friable-to-firm; small whitish specks of pumice sand visible throughout this horizon; weakly development medium, coarse and fine blocky structure, breaking to granules; slightly sticky and moderately plastic when moist; boundary distinct,
on..	very stony, very gravelly sandy clay loam, compact and hard when dry; uppermost part weakly cemented with silica, clay and perhaps iron; rounded stones are but little weathered; thin iron-pan at 160 cm, about 1/2 cm in thickness and passing around stones; below iron pan is thick bed of clayey, stony material resembling glacial till.

Profile No. 30 - Puerto Fonck very fine sandy loam

Location : 1 km east of Puerto Fonck, Osorno Province.
Altitude : about 70 metres.
Relief : rolling.
Parent material: mixed andesitic and rhyolitic volcanic ash.
Plant cover : roadside grasses, formerly forest.

Profile

0 - 30 cm — very dark brown (10YR 2/2, moist; gray brown, 10YR 5/2, dry) very fine sandy loam; friable; weakly developed coarse blocky structure breaking readily to very fine granules and crumbs; non-sticky and non-plastic when moist; boundary diffuse, (pH 5.8),

30 - 50 cm — dark yellowish brown (10YR 4/4, moist; yellowish brown, 10YR 5/4, dry) loam; very friable, soft and quite loose when dry; very weakly developed medium and fine blocky structure breaking to fine granules; slightly sticky and moderately plastic when moist; boundary merging, (pH 5.8),

50 - 65 cm — yellowish brown (10YR 5/6, moist; pale brown, 10YR 6/3, dry) clay loam; very friable to friable; weakly developed blocky structure breaking to coarse and fine granules; slightly sticky and slightly plastic when moist; boundary diffuse, (pH 5.9),

65 - 110 cm — yellowish brown (10YR 5/8, moist; light yellowish brown, 10YR 6/4, dry) loam; very friable but moderately compact in place; no visible structure in the mass, but breaks to granules and crumbs under firm pressure; slightly sticky and slight-to-moderately plastic when moist; boundary abrupt, (pH 6.0),

110 - 190 cm — dark yellowish brown (10YR 4/4, moist) sandy clay loam; friable; weakly developed very coarse blocky structure, breaking to fine blocks and granules; line of brownish yellow (approximately, 10YR 6/8) hard lumps of sandy loam crosses this horizon at about 130 cm depth from surface; slightly sticky and moderately plastic when moist; the natural colour of many of the peds is slightly more reddish (i.e. about 7.5YR 5/6) but on crushing these change to the predominant colour, 10YR 4/4; boundary diffuse,

on.. — very compact yellow (10YR 7/6) coarse sandy clay loam with many weathering lumps of pumice and some fragments of weathering andesite. Glacial gravels appear at about 300 cm from the surface.

Profile No. 31 - Puerto Fonck silt loam

Location : about 10 km before the end of the Lake Rupanco road, Osorno Province.
Altitude : about 200 metres.
Relief : rolling.
Parent material: andesitic volcanic ash.
Plant cover : forest, with ulmo, laurel, arrayán, etc.

Profile

0 - 10 cm black (10YR 2/1, moist; very dusky red, 2.5YR 2/2, dry) somewhat peaty silt loam; very friable; very strongly developed crumb structure; very numerous roots; non-sticky and non-plastic when moist; boundary distinct,

10 - 50 cm very dark reddish brown (5YR 2/2 - 2/1, moist; dark brown, 7.5YR 3/2, dry) heavy silt loam; firm-to-friable; strongly developed medium and fine blocky structure breaking to fine granules; slightly sticky, slight-to-moderately plastic when moist; boundary distinct,

50 - 70 cm black to very dark reddish brown (5YR 2/1 - 2/2, moist; almost the same colour, perhaps a little browner, dry) fine sandy loam; friable; no visible structure in the mass but breaks very easily to fine granules and crumbs; very slightly sticky and slightly plastic when moist; boundary diffuse,

70 - 120 cm about dark brown to dark yellowish brown (10YR 3/3, moist; dark yellowish brown, 10YR 4/4, dry) silt loam with many very small fragments of pumice; friable-to-firm; no visible structure in the mass but breaks readily to very fine granules and crumbs; slightly sticky and moderately plastic when moist; boundary distinct,

on.. dark yellowish brown silty clay loam; succeeded by similar strata ranging from silty clay to coarse sandy clay loam with weathering pumice gravel; some layers compact, some quite loose.

Profile No. 32 - Puyehue silt loam

Location : 8 km south of Puyehue township, Osorno Province.
Altitude : about 550 metres.
Relief : strongly rolling.
Parent material: andesitic volcanic ash mainly.
Plant cover : forest, with tepa, ulmo, arrayán, picha, etc.

Profile

0 - 15 cm very dark brown to black (10YR 2/2 - 2/1, moist; very dark brown, 10YR 2/2, dry) silt loam; friable; moderately developed medium and coarse subangular blocky structure, breaking to fine granules; slightly sticky and slightly plastic when moist; numerous very fine whitish fragments of pumice; boundary diffuse, (pH 6.0),

15 - 38 cm very dark brown (10YR 2/2, moist; very dark grayish brown, 10YR 3/2, dry) silt loam; friable; moderately developed medium and fine subangular blocky structure, breaking to very fine blocks and coarse granules; slightly sticky and slightly plastic when moist; boundary distinct, (pH 6.0),

38 - 60 cm very dark brown to very dark grayish brown (10YR 2/2 - 3/2, moist; dark grayish brown, 10YR 4/2, dry) loam; friable-to-firm; moderately developed medium and fine subangular blocky structure breaking to coarse granules; these granules break further under very slight pressure to very fine grains; very slightly sticky and very slightly plastic when moist; boundary merging, (pH 5.8),

60 - 90 cm very dark brown (10YR 2/2 - 3/2, moist; dark brown, 10YR 3/3, dry) silt loam; friable when moist, soft when dry; strongly developed fine subangular blocky structure, breaking to granules; slightly plastic and slightly sticky when moist; boundary diffuse, (pH 5.7),

90 - 150 cm very dark brown (10YR 2/2, moist; dark brown, 10YR 3/3, dry) silt loam with an abundance of fine black mineral particles; friable; structure as for last horizon; slightly sticky, slight-to-moderately plastic when moist; boundary diffuse, (pH 6.0),

150 - 188 cm dark brown (7.5YR 3/2, moist; dark yellowish brown, 10YR 4/4, dry) loam; moderately developed medium subangular blocky structure breaking very easily to granules and crumbs; non-sticky and non-to very slightly plastic when moist; boundary merging, (pH 6.1),

188 - 250 cm dark brown (7.5YR 3/2, moist; dark yellowish brown, 10YR 4/4, dry) heavy loam; friable-to-firm, slightly hard when dry; weakly developed medium blocky structure, breaking to coarse granules; non-sticky and very slightly plastic when moist; boundary distinct, (pH 6.3),

on.. mainly dark brown to brown stratified ash beds, some with slightly reddish brown colour; textures loam to clay loam; some strata slightly compact.

Profile No. 33 - Choshuenco sandy loam

Location : Chan-Chan Estate, at head of Lake Panguipulli, Valdivia Prov.
Altitude : 850 metres.
Relief : strongly rolling to hilly.
Parent material: basic andesitic ash.
Plant cover : forest, with roble, olivillo, ulmo, quila, etc.

Profile

0 - 5 cm	black (2.5YR 2/0, moist) peaty sandy loam with many decomposing forest residues; very friable; crumb structured; non-sticky and almost non-plastic when moist; boundary distinct,
5 - 25 cm	very dusky red to black (2.5YR 2/2 - 2/0, moist) slightly peaty sandy loam; very friable; strongly developed very fine subangular blocky and granular structure; non-sticky and non-plastic when moist; boundary distinct,
25 - 45 cm	dark reddish brown grading to very dark grayish brown (5YR 2/2 grading to 10YR 3/2, moist) gravelly loamy sand; very friable and loose when moist; many large pumiceous and scoriaceous fragments; no distinct structure; non-sticky and non-plastic when moist; boundary distinct,
on..	various strata of ash beds and shower layers, of general yellowish-red colour (5YR 4/6, moist) but with some pale yellowish and highly pumiceous, and others nearly black basaltic loamy sand; wide range in texture, compaction and consistence.

Profile No. 34 - Rupanco gravelly coarse sandy loam

Location : at far end of Lake Rupanco road about 15 km west of Gaviota, Osorno Province.
Altitude : about 275 metres.
Relief : rolling to gently rolling.
Parent material: rhyolitic (pumiceous) volcanic ash.
Plant cover : forest with laurel, ulmo, etc.

Profile

0 - 45 cm black (5YR 2/1, moist; dark gray, 5YR 4/1, dry) gravelly coarse sandy loam; friable; weakly developed fine granular structure; non-sticky and non-plastic when moist; boundary merging,

45 - 65 cm very dark brown (10YR 2/2, moist; grayish brown, 10YR 5/2, dry) gravelly loamy sand; rather firmly packed; no visible structure in the mass but breaks to weakly developed very fine granular structure with many single grains, some of which are clearly pumiceous; non-sticky and non-plastic when moist; boundary clear and wavy,

65 - 150 cm brown to strong brown (7.5YR 4/4 - 5/6, moist; yellow, 10YR 7/6, dry) coarse gravel, wholly pumiceous; firm and tightly packed but breaks when loosened into separate pumice fragments; non-sticky and non-plastic when moist; pumice is only very slightly softened by weathering; boundary abrupt,

150 - 195 cm brown (10YR 4/3, moist; light yellowish brown, 10YR 6/4, dry) sandy clay loam with occasional soft pumice fragments; friable-to-firm; very weakly developed blocky structure, breaking to fine granules; non-sticky and very slightly plastic when moist; boundary distinct,

on.. dark yellowish brown (10YR 4/4, moist; brownish yellow, 10YR 6/8, dry) rather heavy gravelly sandy loam with many softened, weathering, pumice fragments; friable-to-firm, somewhat hard when dry; no visible structure in the mass, but breaks irregularly to coarse and medium angular blocks; very slightly sticky, slight-to-moderately plastic when moist; various other pumiceous layers, all showing successive increase in weathering of the pumice occur below 250 metres.

Profile No. 35 - Quillelhue loamy sand

Location : about 79 road miles, east south-east of Pucón on road to Argentina, Cautín Province.
Altitude : about 720 metres.
Relief : strongly rolling.
Parent material: pumiceous volcanic ash, probably mainly rhyolitic.
Plant cover : coigüe forest.

Profile

0 - 15 cm	dark reddish brown (5YR 2/2, moist; brown, 7.5YR 4/2, dry) loamy sand; very friable; strongly developed very fine granular and crumb structure; non-sticky and non-plastic when moist; boundary distinct,
15 - 35 cm	very dark brown (10YR 2/2, moist; pale brown, 10YR 6/3, dry) loamy sand with a few fine pumice fragments; friable-to-firm; very weakly developed very fine granular and crumb structure; loose and soft when dry; non-sticky and non-plastic when moist; boundary distinct,
35 - 110 cm	yellowish brown (10YR 5/8, moist; yellow, 10YR 7/6, dry) tightly packed pumice gravel of rather coarse grade; friable when loosened from the mass; non-sticky and non-plastic when moist; boundary distinct,
110 - 210 cm	dark yellowish brown (10YR 4/4, moist; yellowish brown, 10YR 5/8, dry) slightly gravelly heavy sandy loam to coarse sandy clay loam; firm; weakly developed coarse subangular blocky structure, breaking to fine blocks; slightly sticky and slight-to-moderately plastic when moist; boundary diffuse,
on...	alternating beds and pumice shower layers continuing to over 5 metres; general colour yellow to strong brown when moist; some layers slightly compact, possibly weakly cemented.

Profile No. 36 - Pucón coarse sandy loam

Location : about 28 miles east of Pucón township, Cautín Province.
Altitude : approximately 500 metres.
Relief : strongly rolling.
Parent material: pumiceous rhyolitic volcanic ash.
Plant cover : roadside grasses, formerly forest.

Profile

0 - 15 cm	dark reddish brown (5YR 2/2, moist; brown, 7.5YR 4/2, dry) coarse sandy loam; friable; rather indistinct very fine granular and crumb structure; non-sticky and non-plastic when moist; boundary diffuse,
15 - 30 cm	very dark grayish brown (10YR 3/2, moist; brown, 10YR 5/3, dry) gravelly sandy loam with many small lumps of pumice; very friable, rather loose when dry; weakly developed crumb and granular structure; non-sticky and non-plastic when moist; boundary distinct,
30 - 60 cm	yellowish brown (10YR 5/8, moist; yellow, 10YR 7/6, dry) pumice gravel; rather tightly packed but falls apart very readily in dry road banks; distinct fragments of carbonised woody material occur in the top 1/2 cm of this horizon; non-sticky and non-plastic when moist; boundary abrupt,
60 - 110 cm	strong brown (7.5YR 5/6, moist; dark yellowish brown, 10YR 4/4, dry) loamy sand; rather compact in place but only slightly firm in hand specimens; weakly developed irregular blocky structure; slightly sticky and slightly plastic when moist; boundary distinct,
on..	various strata, including further coarse pumice layers, compact sandy clay loam beds, etc., of general colour yellowish to strong brown but some yellowish red; some pumiceous layers quite hard and probably cemented with silica.

Profile No. 37 - Osorno very fine sandy loam

Location : 8 km southeast of Osorno city, Osorno Province.
Altitude : about 65 metres.
Relief : gently rolling and undulating.
Parent material: mixed andesitic and rhyolitic ash, in part loessic.
Plant cover : roadside grasses, formerly roble forest.

Profile

0 - 15 cm	dark brown (7.5YR 3/2, moist; pale brown, 10YR 6/3, dry) very fine sandy loam; friable; very fine granular and crumb structure; non-sticky and non-plastic when moist; boundary distinct,
15 - 30 cm	dark brown (7.5YR 4/4, moist; yellowish brown, 10YR 5/6, dry) silt loam; very friable; fine sub-angular blocky structure, breaking to crumbs; non-sticky and non-plastic when moist; boundary diffuse,
30 - 50 cm	dark brown (7.5YR 4/4, moist; yellowish brown, 10YR 5/6, dry) silt loam; friable-to-firm, slightly hard when dry; moderately developed medium and fine subangular blocky structure breaking to granules; very slightly sticky and slightly plastic when moist; boundary diffuse,
50 - 70 cm	dark yellowish brown (10YR 4/4, moist; light yellowish brown, 10YR 6/4, dry) heavy silt loam; friable; moderately developed medium and fine subangular blocky structure breaking to coarse and fine granules; slightly sticky, slight-to-moderately plastic when moist; boundary diffuse to merging,
70 - 90 cm	dark yellowish brown to strong brown (10YR 4/4 - 7.5YR 5/6, moist; light yellowish brown, 10YR 6/4, dry) silty clay loam; friable-to-firm; strongly developed medium subangular blocky structure breaking easily to fine blocks and coarse granules; peds rather resistant to pressure and appear to be lightly coated reddish-yellow (7.5YR 6/8, approximately); slightly sticky and moderately plastic when moist; boundary distinct,
90 - 110 cm	strong brown (7.5YR 5/6, moist; light brown, 7.5YR 6/4, dry) heavy silt loam; firm; weakly developed medium blocky structure breaking to very fine subangular blocks which are not so resistant to pressure as those of last horizon; slightly sticky and moderately plastic when moist; boundary abrupt,
on..	strong brown (7.5YR 5/6, moist) gravelly sandy clay loam grading into ancient alluvial beds.

Profile No. 38 - Pelchuquín fine sandy loam

Location :	18.2 km north of Valdivia on the old main highway, and about 54 km south of San José de la Mariquina, Valdivia Province.
Altitude :	about 25 metres.
Relief :	gently undulating.
Parent material:	mainly mixed andesitic and rhyolitic volcanic ash, part alluvial in origin and part loessic.
Plant cover :	roadside grasses, formerly forest.

Profile

0 - 20 cm	brown (7.5YR 4/4, moist; pinkish gray, 7.5YR 6/2, dry) fine sandy loam; friable; very fine subangular blocky structure breaking readily to crumbs; very slightly sticky and slightly plastic when moist; boundary diffuse; (occasional fragments of carbon present),
20 - 40 cm	dark red (2.5YR 4/4 - 4/6, moist; pinkish gray, 5YR 6/2, dry) sandy loam; very friable and difficult to wet; very weakly developed irregular blocky structure, powdering readily to single grains; non-sticky and almost non-plastic when moist; boundary abrupt,
40 - 100 cm	dark yellowish brown (10YR 4/4, moist; yellowish brown, 10YR 5/4, dry) heavy silt loam to silty clay loam; friable-to-firm; moderately developed medium subangular blocky structure, breaking to very fine blocks and granules; slightly sticky and moderately-to-strongly plastic when moist; boundary distinct,
100 - 200 cm	brown (10YR 4/4, moist; light yellowish brown, 10YR 6/4, dry) silty clay; firm to very firm, very hard when dry; very strongly developed coarse blocky structure, breaking under strong pressure to very fine but regular blocks and coarse granules; somewhat prismatic in the weathering roadside banks; moderately sticky and strongly plastic when moist; boundary sharp,
200 - 300 cm	pale yellowish brown (10YR 6/4, moist) cemented siliceous tuff,
on..	compact and slightly cemented gravelly clay of very old alluvial deposits.

Profile No. 39 - Castro silt loam

Location : near Castro airport, Chiloé Island, Chiloé Province.
Altitude : about 50 metres.
Relief : rolling to undulating.
Parent material: mixed andesitic and rhyolitic volcanic ash, probably in part of loessic origin.
Plant cover : formerly forest: now abandoned pasture land.

Profile

0 - 20 cm very dark brown (10YR 2/2, moist; very dark grayish brown, 10YR 3/2, dry) silt loam; friable; moderately developed medium and fine granular structure; very slightly sticky and slightly plastic when moist; water expressed from wet soil is turbid and peaty; when thoroughly dry (as in some road banks in summer) granules will float on water; boundary diffuse, (pH 5.0),

20 - 54 cm very dark brown (10YR 2/3, moist; dark brown, 10YR 3/3, dry) silt loam; friable; moderately developed medium subangular blocky structure breaking to coarse granules; slightly sticky and slightly plastic when moist; boundary merging, (pH 5.0),

54 - 90 cm very dark yellowish brown (10YR 4/4 - 2/2, moist; dark yellowish brown, 10YR 4/4, dry) loam; friable-to-firm; strongly developed medium subangular blocky structure breaking to fine blocks and granules; slightly sticky and slightly plastic when moist; abundant fine whitish, porous siliceous particles; boundary diffuse, (pH 5.0),

90 - 100 cm matrix as last horizon but with included lumps of dark yellowish brown (10YR 4/4, moist; brown to yellowish brown, 10YR 5/3 - 5/4, dry) heavy sandy loam; firm-to-friable when moist but quite hard when dry in road banks; lumps are 7 to 15 cm in diameter, irregular in shape, and merge along their margin into the surrounding matrix of the horizon; they have no visible structure in the mass but break to irregular fine blocks and granules; slightly sticky and slightly plastic when moist; these lumps probably represent the less weathered remnants of an old mud-shower that has passed through a slightly cemented stage, (pH of lumps, 5.3),

100 - 140 cm dark yellowish brown (10YR 4/4, moist or dry) sandy clay loam; firm-to-friable, fairly hard when dry in road banks; weakly developed fine angular blocky structure; slightly sticky, moderately plastic when moist; abundant pale brown porous siliceous particles; boundary merging, (pH 5.3),

140 - 210 cm dark yellowish brown grading to yellowish brown (10YR 4/4 - 5/6, moist; pale brown grading to brown, 10YR 5/3 - 6/3, dry) light sandy clay loam to sandy loam; friable; no visible structure in the mass but breaks to very weakly developed fine blocks and granules; slightly sticky and slightly sticky when moist; boundary distinct, (pH 5.3),

on.. dark brown (10YR 4/3, moist; very pale brown, 10YR 7/3, dry) gravelly coarse loamy sand with manganese oxide coating on surface of gravels; firm, somewhat compact, but crushes under

Profile No. 40 - Quellón silt loam

Location : 4 km northwest of Quellón township, Chiloé Island, Chiloé Prov.
Altitude : about 100 metres.
Relief : gently rolling to rolling.
Parent material: mixed andesitic and rhyolitic volcanic ash.
Plant cover : formerly forest, now reverting shrub land.

Profile

0 - 20 cm black (10YR 2/1, moist; very dark brown, 10YR 2/2, dry) silt loam; friable, slightly hard when dry in road banks; moderately developed medium and fine subangular blocky structure breaking to granules; slightly plastic and slightly sticky when moist; boundary merging, (pH 4.8),

20 - 50 cm very dark brown (10YR 2/2, moist; very dark grayish brown, 10YR 3/2, dry) silt loam; friable-to-firm, rather hard when dry in road banks; moderately developed medium, fine subangular blocky structure and coarse granules; peds rather crisp, very firm when dry; slightly sticky and slightly plastic when thoroughly crushed and moist; boundary merging, (pH 5.0),

50 - 150 cm very dark brown (10YR 2/3, moist; dark brown, 10YR 3/3, dry) silt loam; firm-to-friable, hard when dry in road banks; weakly developed medium and fine subangular blocky structure breaking to coarse granules that are very resistant to pressure; slightly sticky and slightly plastic when crushed moist; boundary distinct, (pH 5.6),

150 - 165 cm yellowish brown (10YR 5/8, moist) heavy silt loam; firm-to-friable, hard when dry in road banks; strongly developed fine subangular blocky structure breaking to granules; slightly sticky and moderately plastic when moist; boundary abrupt, (pH 5.9),

on.. very compact, cemented gravelly heavy clay, resembling glacial till.

Profile No. 41 - Mañiuales silt loam

Location : at km 24.5 on road from Aysén to Coyhaique, Aysén Province.
Altitude : about 150 metres.
Relief : rolling to strongly rolling.
Parent material: mainly subaerial andesitic volcanic ash.
Plant cover : formerly forest (coigüe and lenga mainly), now pasture.

Profile

0 - 17 cm	very dusky red to black (2.5YR 2/2 - 5YR 2/1, moist) silt loam; friable-to-firm; coarse blocky structure, with strong vertical orientation (almost prismatic) when dry in road cuttings; breaking to fine angular blocks and strong coarse granules; non-sticky but very slightly plastic when moist; boundary distinct,
17 - 34 cm	dark reddish brown (5YR 3/4, moist) fine sandy loam; firm-to-friable; coarse subangular blocky structure breaking to strong granules; very crisp peds; non-sticky and non-plastic when moist; boundary distinct,
34 - 40 cm	yellowish-red (5YR 4/6, moist) gravelly sandy loam (pumice gravel); firm, weakly cemented; no visible structure in the mass but breaks to weak angular blocks; non-sticky but very slightly plastic when moist; boundary distinct,
40 - 47 cm	dark reddish brown (2.5YR - 5YR 3/4, moist) coarse sand; friable; no visible structure in the mass but when removed falls into coarse irregular blocks with rather crisp granules; non-sticky and non-plastic when moist; boundary distinct,
47 - 82 cm	reddish-brown (5YR 4/2 - 7.5YR 4/2, moist) very fine sandy loam to silt loam; firm; no visible structure in the mass but breaks to coarse blocks, and these break further to very fine granules and crumbs; non-sticky but slightly plastic when moist; boundary merging,
82 - 150 cm	strong brown to yellowish red (7.5YR 5/6 - 5YR 4/6, moist) silty clay loam; friable-to-firm; coarse blocky structure breaking to granules; non-sticky but slightly-to-moderately plastic when moist; boundary distinct,
on..	bouldery terrace gravels.

Profile No. 42 - Puerto Lumas sandy loam

Location	:	near Chacabuco port, about 6.5 km from Aysén river ferry, Aysén Province.
Altitude	:	about 20 metres.
Relief	:	gently rolling, low saddle between two hills.
Parent material	:	rhyolitic pumiceous volcanic ash.
Plant cover	:	formerly forest, now in rough pasture.

Profile

0 - 18 cm	dark reddish brown (5YR 3/3, moist, but very dusky red, 2.5YR 2/2, when wet) sandy loam; friable; granular structure; non-sticky and very slightly plastic when moist; boundary distinct,
18 - 35 cm	yellowish-brown (10YR 5/8, moist) coarse sandy loam to coarse sandy clay loam; firm-to-friable, weakly cemented; strongly developed medium angular blocky structure breaking to coarse granules; very slightly sticky and moderately plastic when moist; boundary sharp,
35 - 53 cm	brown to yellowish-brown (10YR 5/3 - 5/4, moist) coarse sand; very firm and cemented; pan breaks into irregular chunks and therefore has no internal structure, not laminated; non-sticky and non-plastic when moist; boundary sharp (abrupt),
53 - 55 cm	dark reddish brown (5YR 3/3, moist) coarse sand and fine pumice gravel; loose; single grains; non-sticky and non-plastic when moist; boundary distinct,
55 - 72 cm	brown to dark brown (7.5YR 4/2, moist) heavy coarse sandy loam or coarse sandy clay loam; firm; coarse angular blocky structure breaking to medium and fine blocks; non-sticky but moderately plastic when moist; boundary merging,
72 - 100 cm	strong brown to dark yellowish brown (7.5YR 5/6 - 10YR 4/4, moist) fine sandy clay loam; friable-to-firm; strongly developed coarse blocky structure (weathers to prismatic structure in places) breaking to medium and fine angular blocks and coarse granules; peds crisp and with very thin coating of iron-oxide; non-sticky but moderately plastic when moist; boundary distinct,
on..	gravelly clay, dense, compact and, in places, with very thin iron-pan at junction of soil and gravel beds.

Profile No. 43 - Natri peaty fine sandy clay loam

Location : about 1 mile north of Lake Natri, Chiloé Island, Chiloé Prov.
Altitude : about 80 metres.
Relief : rolling.
Parent material: andesitic volcanic ash.
Plant cover : Nothofagus dombeyi forest.

Profile

0 - 15 cm	forest mor of very dusky red fibrous loamy peat; pH 4.8,
15 - 30 cm	dark reddish-brown (5YR 2/2, moist; very dark gray, 5YR 3/1, dry) fine sandy clay loam, with many light reddish-brown, iron-stained root channels; friable; very strongly developed medium blocky structure, breaking to coarse granules; very slightly sticky and moderately plastic when moist; occasional pale brown fragments of weathered pumice; boundary merging; pH 5.0,
30 - 43 cm	dark reddish-brown (5YR 3/3, moist; dark brown, 10YR 3/3, dry; dark yellowish-brown to brown, 10YR 4/4 - 7.5YR 4/4, when crushed moist) fine sandy clay loam; compact in place, firm when moist, hard when dry; very strongly developed prismatic structure, breaking to medium sized blocks and coarse granules; prisms strongly coated with iron oxide (dark red, 2.5YR 3/6); non-sticky and moderately plastic when moist; boundary merging; pH 5.2,
43 - 90 cm	reddish-brown (5YR 4/4, moist; dark reddish-brown, 5YR 3/4, when crushed moist) silty clay; less compact in place than last horizon, firm-to-friable, hard when dry but inclined to powder under pressure; very strongly developed medium-sized prisms, breaking to fine blocks and granules; slightly sticky and moderately plastic when moist; aggregates strongly coated with iron oxide (dark reddish-brown, 2.5YR 3/4) on all sides virtually forming a weak iron-pan lattice through the soil; occasional fragments of true iron-pan, 2 mm in thickness; boundary merging; pH 5.5,
90 - 115 cm	dark brown to strong brown (7.5YR 4/4 - 5/6, moist) sandy clay loam; faint, occasional mottles (5YR 5/6, yellowish-red); friable, powdering readily when dry; weakly developed blocky structure with faint lamination; slightly sticky and moderately plastic when moist; occasional peds impregnated with iron oxide giving appearance of concretions; boundary sharp; pH 5.8,
on..	coarse gravels and sands, cemented with iron and silica to a depth of 1 metre; true iron pan, 1/2 cm in thickness along surface of gravels; no cementation below 1 metre; material shows alluvial stratification.

Note: Throughout whole profile, there is a scattered occurrence of fine decomposing pumice fragments; and shining, white, rounded very fine quartz gravel, 3 mm to 8 mm in diameter, occasionally forming a distinct line in the soil.

Profile No. 44 - Chepu very fine sandy loam

Location : about 20 km west of Puntra station on track to Chepu, Chiloé Island, Chiloé Province.
Altitude : about 110 metres.
Relief : gently rolling.
Parent material: mixed andesitic and rhyolitic volcanic ash.
Plant cover : forest with abundant Weinmannia trichsperma.

Profile

0 - 5 cm — dusky red (moist) layer of forest litter, mainly undecomposed leaves and twigs of Weinmannia,

5 - 25 cm — black (5YR 2/1, moist) fine sandy loam, distinctly peaty; friable; very strongly developed coarse granular structure and these granules have a great resistance to pressure; when properly crushed, and wet, shows very slight stickness and slight plasticity; boundary distinct,

25 - 35 cm — pinkish gray (7.5YR 6/2, moist; light gray, 10YR 7/2, dry) very fine sandy loam; friable-to-firm, slightly hard when dry in ditch walls; strongly developed medium subangular blocky structure breaking to very even-sized medium granules; slightly sticky and slightly plastic when moist; boundary abrupt,

35 - 35.5 cm — very thin, discontinuous iron-humus pan; fragile but forming a distinct coating around soil aggregates,

35.5 - 70 cm — strong brown to dark yellowish brown (7.5YR 5/6 - 10YR 4/4, moist) heavy silt loam grading to light silty clay loam; friable; very 'greasy' when crushed; weakly developed coarse subangular blocky structure, breaking readily to granules and crumbs; larger aggregates very slightly coated with reddish brown (2.5YR 4/4, moist) iron oxide deposition; slightly sticky and slightly plastic, boundary diffuse,

70 - 90 cm — yellowish brown (10YR 5/6, moist) silty clay loam; friable-to-firm; very weakly developed coarse subangular blocky structure, breaking to irregular medium and fine blocks; very slightly sticky but moderately plastic when moist; boundary distinct,

90 - 100 cm — reddish-yellow (7.5YR 6/8, moist) loamy sand with partial cementation with iron and humus; rather firm; very strong laminar structure; cemented material forms small slabs with stronger coating of iron (and probably manganese) on lower surfaces; non-sticky and non-plastic when moist; boundary abrupt,

on.. — cemented gravels embedded in heavy clay.

Profile No. 45 - Rano Kao heavy fine sandy loam

Location	:	0.8 km south of Mataveri township on lower slopes of Rano Kao volcano, Easter Island (Valparaíso Province).
Altitude	:	45 metres.
Relief	:	long planeze slope of about 7°.
Parent material	:	mainly andesitic scoria overlain by volcanic loess.
Plant cover	:	rough pasture.

Profile

0 - 10"	brown to reddish brown (7.5YR - 5YR 3/3, moist) heavy fine sandy loam; firm to friable and strongly laced with grass roots; moderately developed medium subangular blocky structure breaking to fine angular blocks and coarse granules; very slightly sticky and moderately plastic when moist; boundary merging; (pH 5.9),
10 - 28"	reddish brown (5YR 3/4 - 4/4, moist) clay loam, friable to very friable; massive breaking to very fine granules and crumbs; slight to moderately sticky, moderately to strongly plastic when moist; boundary distinct; (pH 5.8),
18 - 50"	red (2.5YR 4/4, moist) silty clay; firm; weakly developed coarse blocky structure breaking to medium-sized angular blocks and some coarse granules; slightly sticky, moderate to strongly plastic when moist; boundary merging; (pH 5.8),
on..	similar material but lumps of yellowish-red weathered scoria becoming abundant.

Profile No. 46 – Vinapu very fine sandy loam

Location	:	about 1 km southeast of Mataveri township, Easter Island, (Valparaíso Province).
Altitude	:	110 metres.
Relief	:	long planeze slope of volcano, about 9°.
Parent material	:	mainly volcanic ash, in part of loessic origin.
Plant cover	:	rough pasture (possibly originally Sophora scrub forest).

Profile

0 - 12"	dark brown to brown (7.5YR 3/2 - 3/4, moist) very fine sandy loam; friable; no well defined structure in mass but breaking to weakly developed fine blocks granules and crumbs; non-sticky and very slightly plastic when moist; boundary diffuse; (pH 5.4),
12 - 30"	dark brown to dark reddish brown (7.5YR 3/2 - 5YR 3/4, moist) fine sandy clay loam; very friable; no well defined structure in mass but crumbles readily to weakly developed mixture of fine granules and crumbs; non-sticky, slight to moderately plastic when moist; boundary diffuse; occasional carbon fragments at 20"; (pH 5.6),
30 - 60"	reddish brown (5YR 4/4, moist) clay loam; very friable to friable; no well defined structure in mass but breaks to fine granules and crumbs; slightly sticky, moderately plastic when moist; boundary almost distinct; (pH 5.7),
on..	reddish brown (5YR 4/4, moist) silty clay; firm; weakly developed coarse blocky structure; sticky and plastic when moist; boundary not seen; (pH 5.8).

Profile No. 47 - Poike silty clay loam

Location : 0.5 km west of summit of Poike mountain, Easter Island, (Valparaíso Province).
Altitude : 180 metres.
Relief : gently rolling.
Parent material: andesitic ash and andesitic tuff.
Plant cover : rough pasture.

Profile

0 - 15" dark brown (7.5YR 3/2, moist) silty clay loam; firm-to-friable; strongly developed very fine subangular blocky and coarse granular structure; non-sticky and moderately plastic when moist; boundary merging; (pH 5.1),

15 - 30" brown (7.5YR 4/4, moist) silty clay; friable weakly developed medium and fine angular blocky structure; moderately sticky and moderately plastic when moist; boundary merging; (pH 5.0),

30 - 55" reddish brown (5YR 4/4, moist) silty clay; friable but compact 'in situ'; strongly developed fine and very fine angular blooky structure; slight-to-moderately sticky, moderate-to-strongly plastic when moist; boundary diffuse; (pH 4.9),

55 - 70" yellowish-red (5YR 4/8, moist) silty clay; firm-to-friable; weakly developed medium, fine and very fine blocky structure; slightly sticky, moderately plastic when moist; boundary merging; (pH 4.8),

on.. similar, yellowish-red merging to strong brown, silty clay with small lumps of soft weathered tuff.

Profile No. 48 - Pitrufquén heavy sandy loam

Location : approximately 5 km east south-east from Pitrufquén town.
Relief : flattish.
Altitude : about 100 metres.
Parent material: volcanic ash alluvium over alluvial gravels.
Plant cover : second-growth swamp forest with radal and maquis dominant.
Watertable : perched over gravels at about 65 cm below soil surface.

Profile
(notes made on soils in wet condition)

0 - 18 cm dark reddish brown (5YR 2/2) heavy sandy loam; friable but kept in rather compact condition by dense mass of fine roots; very fine granular and crumb structure; non-sticky and very slightly plastic; boundary distinct,

18 - 36 cm dark brown to dark reddish brown (7.5YR - 5YR 3/2) sandy loam; friable-to-firm in place but friable when removed; no visible structure in the mass but breaks to weakly developed coarse subangular blocks, and these break further to very fine angular blocks and coarse granules; very slightly sticky, slightly plastic; boundary diffuse,

36 - 56 cm dark reddish brown grading to yellowish red (5YR 3/4 - 4/6) sandy loam; rather firm in place but when loosened proves to be very friable; very weakly developed coarse blocky structure breaking very readily to medium and fine angular blocks, and further to rather fine granules; these ultimate peds are well-formed and have a slightly 'crisp' feel; non-sticky and slightly plastic; boundary distinct,

56 - 65 cm strong brown grading to dark brown (7.5YR 5/6 - 3/2) sandy loam, slightly heavier than last horizon; firm, quite compact in place; in roadside banks has a distinct prismatic structure, but in the field pit this appears only as a regular coarse blocky structure, which break under firm pressure to medium and fine angular blocks which are quite resistant to further pressure; peds have a distinct 'crisp' feel; non-sticky and very slightly plastic; boundary abrupt,

65 - 170 cm compact gravels and coarse sand, with some heavy clay; gravels are strongly coated on their upper surfaces with a deposit of yellowish red to strong brown oxides,

170 - 290 cm dark gray loose river gravels and sand; distinct alluvial bedding.

Profile No. 49 - Frutillar silt loam

Location : approximately 1 km northwest of Los Pellines Station, Llanquihue Province.
Altitude : 140 metres.
Relief : very gently undulating to flattish; hummocky and with some distinct pond-like depressions.
Parent material: mixed volcanic ash; in part subaerial shower materials.
Plant cover : typical ñadi swamp forest.

Profile

0 - 8 cm very dark brown (10YR 2/2, moist; very dark gray brown, 10YR 3/2, dry) silt loam; friable, distinctly hard when dry; moderately to strongly developed fine granular structure which is very difficult to re-wet when once thoroughly dry; slightly plastic and slightly sticky when moist; boundary diffuse, (field pH 5.4),

8 - 20 cm very dark brown (10YR 2/2, moist; very dark gray, 10YR 3/1, dry) silt loam to very fine sandy loam; friable, but slightly hard when dry, and peds very hard when dry; strongly developed medium subangular blocky structure, breaking readily to very fine angular blocks and granules; ultimate peds very hard when dry and difficult to re-wet, distinctly 'crisp' when moist; slightly plastic and slightly sticky when moist; boundary distinct, (field pH 5.5),

20 - 40 cm dark brown (7.5YR 3/2, moist; brown to dark brown, 10YR 4/3, dry) heavy silt loam; friable to very friable, but when dry consists of rather hard peds loosely packed together; moderately developed medium subangular blocky structure, breaking readily to coarse granules when moist but resisting further disruption when dry; dry blocks very hard to re-wet if thoroughly dry; slightly sticky and slightly plastic when moist (N.B. in farmed soils, this horizon is often compact); boundary diffuse, (field pH 5.6),

40 - 60 cm dark reddish brown (5YR 3/3, moist; dark yellowish brown, 10YR 4/4, dry) heavy silt loam; firm, hard when dry; strongly developed coarse, regular angular blocky structure which appears as well-developed prismatic structure in dry road banks, moist blocks break further to medium subangular blocks and coarse granules; dry prisms are very hard and will not easily break further; moderately sticky and slightly plastic when moist; occasional development of reddish brown (5YR 4/4, moist) medium-sized, diffuse mottles; boundary diffuse, (field pH 5.8),

60 - 80 cm   brown with distinct patches strong brown (10YR 4/3, 7.5YR 4/6, moist; brownish yellow, 10YR 6/8, dry) silty clay loam with occasional small stones; firm, hard when dry; very coarse regular angular blocky structure which dries to well-formed coarse prisms and these resist further pressure; in moist soil coarse blocks with some coarse granules, but peds all rather 'crisp'; moderately sticky and moderately-to-strongly plastic when moist; boundary merging, (field pH 5.8),

80 - 95 cm   strong brown (7.5YR 5/6, moist; yellowish brown, 10YR 5/8, dry) silty clay loam with occasional small stones; firm, hard when dry; strongly developed medium subangular blocky structure that tends to dry out as small regular prisms in dry road banks; dry prisms resist further pressure, but moist blocks break to very fine angular blocks and coarse granules; occasional clay flows visible on larger blocks but not on ultimate peds; moderately sticky and moderately plastic when moist; boundary abrupt, (field pH 6.0),

on..   pale yellow (2.5YR 7/4, moist) very compact coarse gravel with interstices filled with heavy clay and coarse sand; upper part of this alluvial material is trongly mottled with deposition of reddish yellow (5YR 6/8, moist) oxides, especially in vicinity of stones, but with depth this disappears and below 150 cm general colour is light brownish gray (2.5YR 6/2), (field pH 5.8).

Profile No. 50 - Carel fine sandy loam

Location : approximately 6 km west of Los Pellines station, Llanquihue Prov.
Relief : almost level low terrace with slightly hummocky micro-relief.
Altitude : 110 metres.
Parent material: rather silty volcanic materials, in part shower material but mainly alluvial, over alluvial gravels.
Plant cover : cultivated ground, about 30 years out of forest.

Profile

0 - 15 cm very dark brown (10YR 2/2, moist; very dark gray brown, 10YR 4/2, dry) fine sandy loam; friable, hard when dry; moderately developed medium granular structure; slightly plastic and slightly sticky when moist; when dry the peds are very difficult to re-wet; when moist the peds are very 'crisp'; boundary distinct, (field pH 6.0),

15 - 35 cm dark brown (10YR 3/3, moist; brown, 10YR 5/3, dry) loam; friable when moist, hard when dry; strongly developed fine subangular blocky structure breaking to very fine angular blocks and coarse granules; moderately sticky and moderately plastic when moist; boundary distinct, (field pH 6.0),

35 - 50 cm dark brown (7.5YR 4/4, moist; brownish yellow, 10YR 5/4, dry) heavy silt loam to silty clay loam; friable, hard when dry; weakly developed coarse prismatic structure breaking readily when moist to fine subangular blocks; slightly sticky and moderately plastic when moist; boundary diffuse, (field pH 5.8),

50 - 70 cm strong brown (7.5YR 5/8, moist; brownish yellow, 10YR 6/8, dry) silty clay loam to light clay loam; friable, hard when dry; weakly developed coarse prismatic structure breaking when moist to medium and fine blocks; all peds show well-developed clay-skins; slightly sticky and moderately plastic when moist; boundary distinct, (field pH 5.6),

70 - 80 cm strong brown (7.5YR 5/8, moist; brownish yellow, 10YR 6/8, dry) heavy silty clay loam; friable-to-firm, hard when dry; weakly developed fine subangular blocky structure with many clayskins; moderately sticky and moderately plastic when moist; patches of fine gravel occur in this horizon; boundary abrupt, (field pH 5.8),

80 - 80.5 cm thin, continuous, very hard and cemented iron-pan,

on.. very dark grayish brown (2.5YR 3/2, moist; very pale brownish gray, 10YR 6/2 - 7/3, dry) very stony and gravelly coarse sandy loam; very compact to cemented but non-sticky and non-plastic when moist; becoming more sandy, more strongly cemented and with iron-oxide deposition around gravels below 140 cm.

Profile No. 51 - Calonje very fine sandy loam

Location : near km 20 on Ancud-Castro highway, Chiloé Island, Chiloé Prov.
Altitude : about 80 metres.
Relief : level to slightly undulating.
Parent material: alluvial and subaerial volcanic ash.
Plant cover : mainly second-growth shrubby vegetation.

Profile

0 - 20 cm	very dark brown to black (10YR 2/2 - 2/1, moist) rather heavy fine sandy loam; friable, rather hard when dry; strongly developed granular structure; slightly sticky and slightly plastic when moist; peds are very 'crisp' when moist and very hard indeed when dry; boundary merging,
20 - 30 cm	very dark brown (10YR 2/2, moist) fine sandy clay loam; friable-to-firm when moist, very hard when dry; strongly developed fine blocky structure breaking to very fine blocks and coarse granules; peds very crisp when moist, very hard when dry; slightly sticky and moderately plastic when moist; boundary distinct,
30 - 38 cm	dark gray (10YR 4/1, moist) silty clay with occasional very fine rounded gravels; friable when moist; slightly hard when dry; very coarse weakly developed subangular blocky structure when moist, but dries to distinctive coarse prisms; prisms break rather readily when dry to coarse granules, blocks break when moist to fine angular blocks and coarse granules; slightly sticky and slightly plastic when moist; boundary distinct,
38 - 53 cm	dark grayish brown (10YR 4/2, moist) light clay; firm, very hard when dry; no visible structure in the mass but breaks to irregular angular blocks under firm pressure; moderately sticky and moderately-to-strongly plastic when moist, boundary distinct,
53 - 72 cm	brown (10YR 5/3, moist) clay with rounded gravels; firm, very hard when dry; no visible structure in the mass and does not give a well-defined structure when broken; slightly sticky and strongly plastic when moist; boundary abrupt,
on..	pale yellowish brown (dry) or olive (5YR 4/3, moist) gravelly loamy sand grading to reddish brown, iron-stained gravels at about 120 cm.

Profile No. 52 - Chillán sand, intergrading to Santa Bárbara sandy loam

Location : 2 km west of Termas de Chillán, Ñuble Province.
Altitude : about 2000 m.
Relief : moderately steep hill slope.
Parent material: andesitic volcanic ash
Plant cover : Nothofagus forest.

Profile

0 - 10 cm dark reddish brown (5YR 3/2, moist; brown, 7.5YR 4/4, dry) coarse sand; very friable; no visible structure; non-sticky and non-plastic when moist; boundary diffuse,

10 - 15 cm dark brown (7.5YR 3/2, moist; brown, 7.5YR 4/4, dry) slightly loamy coarse sand; friable; no visible structure; non-sticky and non-plastic when moist; boundary distinct,

15 - 50 cm very dark brown (10YR 2/2, moist; yellowish brown, 10YR 5/6, dry) loamy sand; friable; weakly developed coarse granular structure; very slightly sticky but non-plastic when moist; boundary distinct,

50 - 70 cm dark brown (10YR 4/3, dry; dark reddish brown, 5YR 3/3, moist) sandy loam; friable; weakly developed fine subangular blocky structure; non-sticky and very slightly plastic when moist, boundary distinct,

on.. dark yellowish brown very fine sandy loam, etc., typical of Santa Bárbara soils.

Profile No. 53 - Lonquimay coarse sand, intergrading to Cautín sandy loam

Location : 16 km west of Lonquimay township, Malleco Province.
Altitude : 1460 metres.
Relief : moderately steep lower slopes of Lonquimay volcano.
Parent material: basic andesitic volcanic ash.
Plant cover : Araucaria forest.

Profile

0 - 8 cm	black (5YR 2/1, moist; very dark gray, 7.5YR 3/0, dry) coarse sand and scoriaceous gravel; very friable to loose; no recognisable structure; non-sticky and non-plastic when moist; boundary distinct,
8 - 23 cm	light gray (10YR 6/1, moist; very pale brown, 10YR 7/3, dry) very fine scoriaceous gravel, almost pumiceous; very friable; no recognisable structure but laminated in place; non-sticky and non-plastic when moist; boundary abrupt,
23 - 70 cm	dark yellowish brown (10YR 4/4, moist; yellowish brown, 10YR 5/4, dry) pumiceous sand; very friable; very weakly developed fine subangular blocky structure; non-sticky and non-plastic when moist; boundary distinct,
70 - 100 cm	very dark gray (10YR 3/1, moist; gray, 10YR 5/1, dry) sandy loam; friable; very fine granular structure; non-sticky and very slightly plastic when moist; boundary distinct,
100 - 150 cm	very dark brown (7.5YR 3/2, moist; brown, 7.5YR 4/4, dry) very fine sandy loam; firm-to-friable; strongly developed coarse blocky structure; very slightly sticky and slightly plastic when moist; boundary diffuse,
on..	brown to strong brown silty clay loam, etc., typical of many Cautín soils.

Profile No. 54 - Villarrica coarse sand, intergrading to Pucón loamy sand

Location	:	about 5 km before end of Villarrica Refugio road, Cautín Prov.
Altitude	:	about 1500 metres.
Relief	:	very strongly rolling to moderately steep.
Parent material	:	pumiceous rhyolitic volcanic ash.
Plant cover	:	Nothofagus forest.

Profile

0 - 5 cm	dark reddish brown (5YR 3/2, moist; light brownish gray, 10YR 6/2, dry) loamy coarse sand; friable; no recognisable structure; non-sticky and non-plastic when moist; boundary distinct,
5 - 18 cm	brown to dark brown (7.5YR 4/3, moist; pale grayish brown, 10YR 5/2, dry) gravelly loamy sand; very friable to loose; no recognisable structure; non-sticky and non-plastic when moist; boundary distinct,
18 - 30 cm	dark reddish brown (5YR 3/2, moist; brown, 7.5YR 4/2, dry) coarse loamy sand; friable; weakly developed fine granular structure; non-sticky and non-plastic when moist; boundary diffuse,
on..	brown grading to yellowish brown pumiceous gravelly sand typical of Pucón soils.

Profile No. 55 – Antillanca stony sand, intergrading to Chanleufú soils

Location : about 1/2 km from Antillanca Refugio, Osorno Province.
Altitude : 1550 metres.
Relief : moderately steep to steep slopes of Casablanca volcano.
Parent material: mainly basaltic volcanic ash.
Plant cover : Nothofagus forest.

Profile

0 - 7 cm	black (10YR 2/1, moist; very dark gray, 10YR 3/1, dry) coarse scoriaceous sand; loose; no recognisable structure but laminated during deposition; non-sticky and non-plastic when moist; boundary distinct,
7 - 10 cm	gray (10YR 5/1, moist; very pale brown, 10YR 7/3, dry) sand and fine scoriaceous gravel; friable; no recognisable structure; non-sticky and non-plastic when moist; boundary distinct,
10 - 25 cm	very dark brown to dusky red (7.5YR 3/2 to 2.5YR 2/2, moist; brown to dark brown, 7.5YR 4/4 to 10YR 2/2, dry) loamy sand; weakly developed granular structure; very slightly but non-plastic when moist; boundary diffuse,
25 - 35 cm	dark reddish brown (5YR 3/2, moist; reddish brown, 5YR 4/3, dry) coarse sandy loam; friable; weakly developed coarse granular structure; slightly sticky and slightly plastic when moist; boundary diffuse,
on..	very dark gray brown (10YR 3/2, moist; yellowish brown, 10YR 5/6, dry) coarse sandy loam grading to sandy clay loam, etc., typical of Chanleufú subsoils.

Profile No. 56 - Collipulli sandy loam (Intergrade between Collipulli soils and Santa Bárbara soils)

Location : about 6 km east of township of Collipulli, Malleco Province.
Altitude : 260 metres.
Relief : gently undulating.
Parent material: andesitic volcanic ash over older volcanic ash or loess.
Plant cover : roadside grasses and shrubs.

Profile

0 - 5 cm	dark brown (7.5YR 3/2, moist, brown, 7.5YR 4/4, dry) sandy loam; friable-to-firm; no recognisable structure in the mass but breaks to irregular fine subangular blocks and coarse granules non-sticky and very slightly plastic when moist; boundary distinct,
5 - 15 cm	dark reddish brown (5YR 3/2, moist; reddish brown, 5YR 4/4, dry) sandy clay loam; firm-to-friable; strongly developed coarse granular structure; slightly sticky and moderately plastic when moist; boundary diffuse,
15 - 60 cm	dark reddish brown (2.5YR 3/4, moist; reddish brown, 2.5YR 4/4, dry) clay loam to clay; strongly developed medium angular blocky structure breaking to fine granules; moderately sticky and strongly plastic when moist; boundary diffuse,
60 - 140 cm	reddish brown to red (2.5YR 4/4 to 4/6, moist; weak red, 2.5YR 5/2, dry) compact clay with very strong coarse blocky structure when separated from the mass; sticky and very plastic when wet; boundary diffuse,
on..	dark brown heavy plastic clay with occasional fragments of weathered andesite boulders.

Profile No. 57 - <u>Maquehue loam</u> (Intergrade between Padre las Casas and Cautín soils)

Location	:	about 20 km southwest of Temuco, Cautín Province.
Altitude	:	about 150 metres.
Relief	:	rolling.
Parent material	:	mainly andesitic volcanic loess and ash.
Plant cover	:	roadside grasses; formerly roble forest.

<u>Profile</u>

0 - 25 cm	dark brown (7.5YR 3/2, moist; brown, 7.5YR 4/4, dry) loam with slight sandy feel; friable to very friable; moderately developed coarse granular structure; non-sticky and non-plastic when moist; boundary diffuse,
25 - 55 cm	dark yellowish brown (10YR 4/4, moist; brown, 10YR 5/3, dry) fine sandy loam grading to heavy loam; friable-to-firm; weakly developed coarse and medium subangular blocky structure breaking to irregular granules; slightly sticky and slight-to-moderately plastic when moist; boundary distinct,
55 - 95 cm	yellowish brown (10YR 5/6, moist; brownish yellow, 10YR 6/8, dry) heavy sandy clay loam; firm; strongly developed coarse blocky (verging on prismatic) structure, breaking further to medium and fine blocks and coarse granules; slight-to-moderately sticky and moderately-to-strongly plastic when moist; boundary distinct,
on..	reddish brown heavy clay, sticky and plastic when moist.

Profile No. 58 - Freire silty clay loam (Intergrade between Ñadi soils and Humic Gley soils)

Location : about 5 km north of Freire township, Cautín Province.
Altitude : 100 metres.
Relief : flattish to very slightly undulating.
Parent material: volcanic alluvium, mainly andesitic.
Plant cover : roadside grasses; formerly forested.

Profile

0 - 35 cm	very dark gray (10YR 3/1, moist; grayish brown, 10YR 5/2, dry) silty clay loam; friable; strongly developed granular structure; slightly sticky and moderately plastic when moist; boundary distinct,
35 - 55 cm	dark brown (7.5YR 3/2, moist; brown, 7.5YR 4/4, dry) clay loam; very weakly mottled dark gray and yellowish brown; friable-to-firm; strongly developed medium and fine subangular blocky structure; slightly sticky and moderately plastic when moist; boundary distinct,
55 - 80 cm	brownish yellow (10YR 6/8, moist; yellow, 10YR 7/6, dry) clay; firm; strongly developed very fine angular blocky structure, with peds showing distinct 'crispness'; moderately sticky and strongly plastic when moist; boundary distinct,
80 - 90 cm	brown (10YR 4/3, moist; pale brown, 10YR 6/2, dry) slightly stony clay; firm, compact; weakly developed coarse blocky structure breaking to granules; moderately sticky and moderately plastic when moist; boundary abrupt,
on..	compact gravel and clay.

Profile No. 59 - Maldonado peaty sandy loam (Intergrade between Ñadi soils and Podsolic Gleys)

Location : Maldonado plateau, Chiloé Island, Chiloé Province.
Altitude : 900 metres.
Relief : very gently undulating.
Parent material: subaerial volcanic ash over micaschist.
Plant cover : tall tussock grassland; formerly forest.

Profile

0 - 5 cm	dark brown (10YR 4/3 - 2/2, moist; dark grayish brown, 10YR 4/2, dry) peaty sandy loam; friable; very weakly developed coarse irregular blocky structure breaking easily to granules and crumbs; non-sticky and very slightly plastic when moist; boundary distinct,
5 - 20 cm	strong brown (7.5YR 5/6, moist; light brown, 7.5YR 6/4, dry) loamy coarse sand; very firm, weakly cemented, very hard when dry; root channels lined with dark reddish brown (5YR 3/2, moist) colour giving soil appearance of mottle; laminated structure, breaking to flattened granules; very slightly sticky but very strongly plastic when moist; boundary distinct,
20 - 30 cm	light gray (10YR 6/1, moist; very pale brown, 10YR 7/4, dry) clay loam; mottled and streaked with light red (2.5YR 6/8, moist), mainly following root channels and natural structural cracks; firm; no visible structure in the mass, but breaks along laminar lines of weakness, and the flattened fragments break further to very fine subangular blocks and granules; slightly sticky and moderately plastic when moist; boundary distinct,
30 - 38 cm	greenish gray (5YR 4/2, moist; pale olive, 5Y 6/4, dry) coarse micaceous loamy sand with quartz fragments; friable; iron-oxide staining on many quartz fragments; no visible structure in the mass but breaks to medium angular blocks; slightly sticky and slightly plastic when moist; boundary abrupt,
on..	weathering micaschist with many quartz veins; general texture gravelly sandy clay loam; iron-oxide coating on many rock fragments and some accumulation of humus in the fissures of the weathering rock.

THE RED VOLCANIC CLAYS OF CHILE

In Chile there is a large group of soils known as the 'Rojos Arcillosos' which have been related, by visiting pedologists, with the world soil group known as Red-Brown Lateritic soils. Some of these soils are derived derived directly from granitic rocks, micaschists, and even Early Tertiary marine sediments; others are derived from andesitic and basaltic volcanic rocks, while a third sub-group are apparently derived from a strongly weathered superficial drift deposit which, in all probability, consisted largely of volcanic ash or volcanic 'loess' containing originally a high proportion of volcanic glass and associated minerals. It is not proved beyond doubt that these latter soils are basically derived mainly from volcanic glass, but the probability is very strong.

In comparison with Trumao and Ñadi soils, the Red Volcanic Clays are not so obviously stratified, yet they do show horizontal discontinuities in texture, colour, structure etc., and in the laboratory it can be demonstrated that the pattern of the residual minerals also changes in conformity with the field characteristics. Commonly, these soils occur on undulating to rolling landscapes of low relief; but they are also found on strongly rolling to hill landforms in the Andean pre-cordillera. In most cases, the discontinuities that are thought to be indicative of depositional stratificaction tend to follow faithfully the curves of the landform. From time to time, the occurrence of thin strata of a pronouncedly different colour or texture, gives the impression of a mud-shower horizon, formerly in a cemented state, but now very thoroughly weathered. By no means all the Red Volcanic Clays have originated from a ash mantle or a volcanic loess mantle, but it is very likely that some of them are so derived.

Granted this probability, then it follows that the present soils must represent a further stage in the weathering of volcanic glass, one in which all or most of the allophane formed in the first stages of weathering has now been converted into crystalline clay minerals such as kaolinite, gibbsite and halloysite-kaolinite intergrades.

In many parts of the south-central sector of the Andean cordillera, where the stratigraphic soil column shows a continuous sequence of volcanic ash of increasing age from above downwards, the lowermost strata are weathered to a stage approximately equal to the Red Volcanic Clay soils of the lowlands. In these soil columns, there is a gradual progress from the uppermost (allophanic) soil, to buried soil materials that show, first a rise in halloysite and metahalloysite in the clay fraction, then the appearance of kaolinitic clays, until the oldest may show almost complete dominance of kaolin (often with gibbsite). The situation on the lowlands is somewhat different. In certain areas there is inter-mixture of allophanic and non-allophanic materials, giving an intermediate type of material, but far more commonly there is a sharp discontinuity (Figs. 1 and 2) between the upper allophanic soil, and the deeper materials that are without allophane but very rich in kaolin. Over wide areas, the allophanic surface layers are absent and here the whole soil profile is developed in the reddish kaolinitic material. This sharp discontinuity, which is the rule rather than the exception on the lowlands, suggests that the older drift materials have undergone accelerated weathering during a much wetter and warmer climatic period. It is tempting to think that such weathering may have taken place during one or more of the inter-glacial periods, or during some past time when the influence of the Humboldt current had less control over the climate of Chile than at the present time.

There seems to be no way of proving, even by inference, the validity of the latter suggestion, but some recent field studies (by Weischet and Wright in 1963) in the formerly glaciated regions of Valdivia, Osorno and Llanquihue provinces gives considerable support to the possibility of there have been some accelerated weathering of a drift mantle in the interglacial periods.

Undoubted glacial deposits first appear on the lowlands in Cautín province, and they extend further and further out over the lowlands from the foot of the Andes as one progresses southwards to Chiloé Island. Weischet (1958) recognises four groups of glacial materials belonging to the Quaternary period. <u>The first glaciation</u> brought glacial ice almost to the coast in the southern provinces, and on the retreat of the glaciers morainic, glacial-lacustrine and glacial-fluvial debris was left on the eastern flank of the coastal range. The soils associated with these glacial drift deposits are very highly weathered clays (in part overlain by younger volcanic drift). The presence of abundant gibbsite nodules in the soils, plus the common occurrence of magnetite as the only residual non-clay mineral other than quartz, strongly suggests that the original glacial materials were overlain by a volcanic loess which subsequently underwent very strong weathering. Such as would certainly be the case if the soil had remained in place during the three subsequent interglacial periods.

<u>The second period of glaciation</u> extended out over the lowlands almost as far as the first one, and the associated soils (Fresia, Cudico, Los Ulmos, etc. series) are rather less weathered than the soils associated with the first glaciation (Ñapeco), but are certainly very much older and more weathered than the allophanic Trumao soils. The soil clays are mainly kaolinitic, with some gibbsite and a little halloysite. In many places these soils overlap on to the older soils materials associated with the first glaciation, but the coincidence of boundaries is remarkably good. Again, one is tempted to postulate the covering of the post-glacial landscape with volcanic loess or drift, - the western limit of the materials being somewhat sharply defined by the operation of the onshore (westerly) winds. It is a feature of these soils associated with the second glacial epoch that prominent solifluction features appear with great regularity in the drift materials; in some places two cycles of solifluction can clearly be seen. It is tempting to think that these features may be a further indication of two distinct interglacial periods. <u>The third glacial period</u> brought glaciers again over the lowlands to a point about half way between the foot of the Andes and the coast, and again the associated soils are less weathered than those of the preceding second glaciation, having a far higher proportion of halloysite, less kaolin, and often a little allophane in the clay fraction. The drift materials associated with this third glaciation is often quite thickly mantled by later deposits of volcanic ash and volcanic loess; it is only in the layer immediately in contact with the glacial materials that reflects the true stage of weathering; and in some areas there is unavoidable confusion between this latter material and some of the older subaerial ash deposits. Finally, during the <u>fourth and last</u>

glaciation, there was again glacial ice on the lowlands, but this only extended for a short distance beyond the present limit of the lakes. The ash and volcanic loess deposits associated with these glacial moraines is wholly allophanic in nature. The fluvio-glacial materials and glacial outwash plains formed during this last glaciation are now the location of most of the Ñadi soils, whose upper layers (beyond the accelerating influence of the watertable on weathering) are wholly allophanic.

Thus a review of the soil pattern and subsoil characteristics in the main area of Chile where glacial action extended onto the lowlands, does lend colour to the suggestion that the Red Volcanic Clays owe their nature to accelerated weathering during the passage of one or more interglacial cycles. The pattern of distribution of the last post-glacial (Trumao) soils lends some support to the idea that aeolian drift rich in volcanic minerals is normally picked up from periglacial zones and redistributed over the glacial landforms through the action of the westerly winds.

There is additional evidence that volcanic materials were actually settling on the frozen landscape during the accumulation of the glacial ice. In both the third and second series of glacial moraines, there are a thick beds of coarse volcanic ash, of intermittent distribution, and showing strong but fine lamination, aligned not horizontally (as it would be in lacustrine or alluvial deposits) but slanting as if they were originally laid down as debris cones. These beds have the local name of 'cancagua'. Cancagua deposits associated with the moraines of the second glaciation are now fairly soft and weathered, whereas those of the third glaciation are still cemented. It is probable that this cementation arose subsequent the release of subaerial ash trapped in the glacial ice, and may be due to the release of silica, calcium and magnesium during the initial weathering processes after the material was emplaced, permitting cementation by silicates. Once cemented, the ash of the cancagua would naturally escape further weathering: in the case of the cancagua associated with the second glaciation, weathering is only now penetrating through the mass; while in the younger cancagua of the third glaciation only the uppermost layers near the soil surface are just now beginning to break down. The cancagua materials thus show retarded weathering in comparison with volcanic drift deposits emplaced before the advance of the ice or after its retreat.

Furthermore the cancagua beds have preserved within their cemented matrix, slabs, chunks and balls of weathered volcanic ash that were first ploughed up by the nose of the advancing glaciers, and then subsequently incorporated in the glacier ice; to be released on the retreat of the glacier simulataneously with the release of any fresh ash trapped in the glacier. In this way the cemented cancagua has preserved fragments of interglacial soil materials. The chunks of soil must have been frozen solid at the time of the advance of the glacier, and they have been preserved to a remarkable degree many of their former soil characteristics. In many cases it is possible to identify soils that have been inverted completely, or turned through 90° from their original orientation. In some cases even the thin iron-pan horizon has been preserved intact. These are not only interesting fragments of fossil soils, but they are relicts that have some possibility of eventually being dated.

Additional evidence for the antiquity of the Red Volcanic Clays is provided by the prevalence of solifluction layers. This is quite apart from the massive solifluction effects that appear to correlate with the penultimate and anti-penultimate interglacial periods; but refers more specifically to relatively minor mass movement on moderately steep slopes. This is a feature rarely shown by allophanic (Trumao) soils which have a far greater capacity for absorbing water, and when frozen extrude the water as long needles. The crystalline clays of the Red Volcanic Soils cannot so readily expel water on freezing, and, when the cold period passes, the mass of wet surface soil sitting on a still frozen subsoil, moves slowly downhill, finally settling down in a more compact mass with its former structure much modified. In this way, on many south-facing slopes near wide riverbeds, where there has been repeated accumulation of aeolian volcanic dust in ancient times, the drift mantle shows layer after layer with solifluction characteristics. In places these show some indication of gradually changing environmental conditions as if solifluction diminished as the landscape became drier or warmer. Since these features are so rarely shown by the allophanic soils, the ash minerals in the aeolian drift must have been in at least a moderately weathered condition at the time of their deposition: possibly they were weathered in the penultimate interglacial period (or earlier), and were eroded, deposited and soliflucted at the sart of the succeeding post-glacial period.

On the balance, the evidence from the four southern provinces where glacial deposits and Red Volcanic Clays occur in conjunction seems strongly to support the hypothesis that these materials owe their present condition to a long history of weathering, intermittently accelerated during warmer interglacial climatic conditions. What, then, of the Red Volcanic Clays of Cautín, and the provinces north to Talca? In this part of Chile, the Red Clays originating from drift materials (as opposed to those clearly derived from underlying rocks) have a rather significant distribution. Near their northern limit, they are confined to the pre-cordillera foothills, and they first emerge on the lowland plain to the south of the Maule river, - appearing as fragmentary patches of, quite possibly, alluvial origin. Further to the south, they are more extensive (see Fig. 4) and may have been derived from volcanic loess or subaerial ash deposits; and, in the vicinity of Collipulli, they extend nearly half way out across the plain. Still more to the south, they extend across the Central Vale as far as the foot of the coastal range, and finally in Cautín province, they extend right to the coast. Northwards along the coast, patches of Red Volcanic Clay occur on many of the older (higher) bench terraces: a pattern of distribution remarkably similar to that shown by the younger Trumao soils. Clearly, much of their former extent has been obliterated by erosion in the Central Vale, but the remnants left do show a clear relation to the known limits of earlier glaciations. North from Villarrica, the western limit of former glacial activity retreated into the Andean cordillera; the limit of the Red Volcanic Clays follows a parallel course some 30 to 40 km further westward. Moreover, the remnants of the Red Volcanic Clays are now found mainly on the older (higher) landforms of the lowlands. The implication is that these soil materials were emplaced long before the last glacial period and thus also have probably undergone accelerated weathering during interglacial cycles.

A typical soil profile of a Red Volcanic Clay near Temuco shows:

0 - 20 cm	dark reddish brown (5YR 3/4, moist; dark brown, 7.5YR 3/4, crushed) heavy silt loam to silty clay loam; friable-to-firm, slightly hard when dry; moderately developed coarse blocky structure, breaking to strongly developed very fine blocky and coarse granular structure, and breaking further to very fine granules; slightly sticky and moderately plastic when moist; boundary diffuse,
20 - 35 cm	dark reddish brown (5YR 3/4, moist; dark reddish brown, 5YR 3/3, crushed) heavy clay loam or light clay; friable-to-firm; rather weakly developed coarse blocky structure, breaking readily to very strong coarse granules; very strongly sticky and moderately strongly plastic when moist; boundary distinct,
35 - 115 cm	dusky red (2.5YR 3/2, moist; dark reddish brown, 5YR - 2.5YR 3/3, crushed) clay; firm to very firm; very strongly developed angular blocky structure with strong vertical fissuring (almost prismatic), breaking to very strongly developed fine angular blocky structure, and finally to very coarse granules; well-developed clayskins on all peds; very strongly sticky and very strongly plastic when moist; boundary distinct,
115 - 200 cm	dusky red to dark reddish brown (2.5YR 3/2 to 5YR 3/3, moist; strong brown, 7.5YR 5/6, crushed) heavy clay; extremely firm, very hard when dry; strongly developed prismatic structure, which can be broken with great difficulty to medium and fine angular blocks; iron and manganese oxides stain the surface of the prisms; clayskins and pressure ridges (similar to slickensides) common on surface of prisms; very strongly sticky and extremely plastic when moist; boundary abrupt,
200 - 230 cm	strong brown (7.5YR 5/8, moist; no change in colour on crushing) clay loam with some fine and medium quartz sand; very firm, hard to the point of being cemented when dry; indistinct irregular fissuring but no other structure when moist, yet peels off in fine prismatic peds on exposure to drying in road banks; few or no clayskins, and no pressure ridges; perforated by many holes and fine tunnels resembling worm or root channels, which are lined with manganese and iron oxides and probably humus; cuts with waxy shine as if containing gibbsite; slight-to-moderately sticky, moderately plastic when moist; boundary abrupt,
230 - 430 cm	dark red to dark reddish brown (2.5YR 3/6 to 3/4, moist; dark reddish brown, 5YR 3/4, crushed) clay; firm to very firm; very strongly developed coarse prismatic structure, breaking with difficulty to medium and fine blocks and very coarse irregular granules; all peds with prominent clayskins and some pressure patterns; occasional deposition of manganese and other sesquioxides on surface of prisms; extremely sticky and plastic when moist, boundary distinct,
on..	dark reddish clay with fragments of weathering andesite, grading into gray soft weathered andesite at about 650 cm.

The above profile illustrates most of the significant features of the Red Clay soils thought to be derived from volcanic drift. There is evident discontinuity in their vertical sequence, especially marked at the 200-230 cm level, where the material has all the typical features of an old mud-shower that became cemented soon after deposition. None of the layers above this shower horizon can have been derived directly from the underlying andesite, and the similarity between the two layers immediately above and below the shower material suggests that even the lower material may not be derived from the andesite below. Apart from a little quartz (abundant only in the shower layer), the chief residual mineral is magnetite. The whole soil profile may well have been built up over a long interval of time from successive accumulation of volcanic dust ('loess'), with occasional additions of subaerial volcanic ash. The soil is clearly very much older than the allophanic Trumao soils that are present in the same region. Kaolin, gibbsite and halloysite are the chief clay minerals in all horizons; gibbsite is present in abundance in the shower horizon, and the lowermost strata are dominantly kaolinitic. The soil described above is Padre las Casas silty clay loam, as developed near Metrenco, Cautín province.

Soils of this type have been described as Red-Brown Lateritic soils and as Rhodocrults. They are quite similar to some of the Brown Granular Clays from volcanic ash described from New Zealand, and their colour (and some structural features) are not dissimilar from the Terra Roxa Estructurada soils of Sao Paulo State in Brazil (S.N.P.A. 1960). In common with these latter soils, the Red Volcanic Clays of Chile are almost impossible to photograph in their (apparent) natural colour.

The Red Volcanic Clays have a cation exchange capacity of 35 or less and usually less than 30% base saturation; the pH ranges from 5.5 downwards, and phosphate fixation is about normal, - nowhere as high as in the allophanic volcanic ash soils. For this reason, they are much more easy to farm and most fertilizers (also lime) give adequate returns. Their tilth is much different from the allophanic soils, but they are well granulated in the topsoil, so that after ploughing the clods rapidly break down to fine granules and form good seedbeds. They are, however, highly susceptible to erosion by water.

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EXPLANATORY LEGEND TO FIG. 4

SUB-HUMID ZONE

REGION 1

"Trumao" Soils

1/1 - From subaerial volcanic ash on foothills
1/2 - From subaerial volcanic ash on rolling downland
1/3 - From volcanic loess on gently undulating high plains
1/4 - From volcanic alluvium on flattish low plain
1/5 - From drift containing volcanic glass on coastal terraces
1/6 - From subaerial pumiceous ash on upland plateau

Steepland "Trumao" Soils

S_1 - Steeplands with occasional patches of volcanic ash
S_2 - Steeplands with thin but continuous mantle of volcanic ash
S_3 - Steeplands with thick mantle of basaltic sandy ash
S_4 - Steeplands with thick mantle of rhyolitic pumiceous ash

"Red Volcanic Clays"

R_1 - From ancient volcanic loess and ash on foothills
R_2 - From ancient volcanic loess on downland
R_3 - From ancient drift deposits on coastal terraces.

HUMID ZONE

REGION 2

"Trumao" Soils

2/1 - From subaerial volcanic ash on foothills
2/2 - From subaerial volcanic ash on rolling downlands
2/3 - From volcanic loess on undulating high plains
2/4 - From volcanic alluvium on flattish low plain
2/5 - From subaerial pumiceous ash, etc. on upland plateau

Steepland "Trumao" Soils

S_4 - Stepplands with discontinuous mantle of volcanic ash
S_4a - Steeplands with thick, continuous mantle of volcanic ash
S_5 - Steeplands with thick, continuous mantle of pumiceous ash

"Red Volcanic Clays"

R_4 - From ancient coastal drift and lacustrine sediments

R_5 - From ancient volcanic loess and andesitic tuffs
R_6 - From ancient volcanic loess of coastal areas

Recent Volcanic Ash Soils

V_1 - From recent andesitic ash
V_2 - From recent basaltic ash, sand and scoria

REGION 3

"Trumao Soils"

3/1 - From subaerial volcanic ash on foothills
3/2 - From subaerial volcanic ash on rolling downland
3/2a- From pumiceous subaerial volcanic ash on downland
3/3 - From volcanic loess on undulating high plains
3/3a- do... older, more weathered, transitional to Red Volcanic clay
3/4 - From volcanic alluvium on flattish low plains
3/5 - do... mixed with recent volcanic ash
3/6 - do... older and more weathered alluvial ash material
3/7 - From drift on coastal terraces
N - Associated "Nadi" Soils

Steepland "Trumao" Soils

S_6 - Steepland thickly mantled in volcanic ash

"Red Volcanic Clays"

R_7 - From ancient volcanic loess
R_8 - From ancient volcanic loess and micaschist

Recent Volcanic Soils

V_3 - From recent volcanic ash, mainly andesitic
V_4 - From recent volcanic ash, mainly basaltic

REGION 4

"Trumao Soils"

4/2 - From subaerial volcanic ash on rolling downland
4/2a- do... in part pumiceous
4/3 - From volcanic loess on ancient glacial landforms
N - Associated "Nadi" Soils

Steepland Soils

S_8 - Steeplands with thick ash mantle, in part pumiceous
S_9 - Steeplands with thick mantle of mixed volcanic ash
S_{10} - Steeplands with thick mantle of pumiceous ash
S_{11} - Steeplands with thick mantle of basaltic ash, etc.

"Red Volcanic Clays"

R_{10} - From ancient volcanic loess and micaschist
R_{11} - From ancient volcanic loess

Recent Volcanic Ash Soils

V_5 - From recent volcanic ash, mixed rhyolitic pumice and andesite
V_6 - From recent basaltic sand and scoria
V_7 - From very recent basaltic ash, sand, scoria and lava
V_8 - From very recent coarse rhyolitic pumice
V_9 - From mixed basaltic and andesitic ash
V_{10} - From andesitic ash, sands and lava

SUPER-HUMID ZONE

REGION 5

"Trumao Soils"

5/2 - From subaerial volcanic ash and loess
5/3 - From volcanic loess
N - Associated "Nadi" Soils

Steepland Soils

S_{12} - Steepland thickly mantled in volcanic ash

Recent Volcanic Ash Soils

V_{11} - From recent pumiceous ash

EXPLANATORY LEGEND TO FIG. 10

ENVIRONMENTAL REGIONS OF THE SOUTHERN ANDEAN ZONE OF SIGNIFICANCE IN CURRENT SOIL FORMING PROCESSES

1. Absolute desert region

   1a. Extremely arid, maximum elevation 2.750 m; no distinct seasonal rhythm of precipitation, high day temperatures, coldest mean monthly temperature in range 10 - 20°C, warmest MMT in range 20-30°C: minimal weathering, minimal leaching, and only weak capillary movement of soluble salts; drift regime locally very active; organic regime minimal: True desert soils (mainly regosolic and lithosolic, with saline accumulation in salares and associated Dry Residual Solonchaks).

   1b. Extremely arid, maximum elevation 1.000 m; no distinct seasonal rhythm of precipitation, regular diurnal condensation of coastal fog humidity, coldest MMT in range 10-20°C, warmest MMT in range 20-30°C: only very slight weathering in soils of oldest and most stable landforms, minimal leaching, strong return of soluble salts to surface by capillary action leading to salt crust formation; drift regime weak; organic regime minimal to very weak: Coastal desert soils and salt crusts.

2. Desert region of lowlands (maximum elevation 3000 m.)

   2a. Arid, no distinct seasonal rhythm of precipitation, moderate to high day temperatures, coldest MMT within range 10-20°C, warmest MMT within range 10-20°C: minimal weathering, minimal leaching, minimal to very weak return of soluble salts by capillary action; drift regime locally quite active; organic regime minimal to very weak: Desertic soils (Regosolic and Lithosolic soils related to Minimal Red Desert soils, with soils that are perhaps Minimal Sierozems and Calcisols.)

   2b. Arid, weak pattern of winter precipitation, high day temperature, coldest MMT within range 10-20°C, warmest MMT within range 20-30°C; weak weathering in immediate subsurface part of soil profile, minimal to very weak leaching, in part nullified by moderately strong capillary return of soluble salts; drift regime locally very active; organic regime very weak: Desertic soils (Minimal and Modal Red Desert soils and related lithosols and regosols, with associated saline alluvial and colluvial soils.)

   2c. Arid, distinct pattern of summer precipitation, high day temperatures, coldest MMT within range 0-10°C, warmest MMT within range 20-30°C: weak to sub-moderate weathering strongest in subsurface part of soil, very weak leaching, moderate to strong capillary return of soluble salts; drift regime locally strong; organic regime weak to very weak: Desertic soils (Modal Red Desert soils and related lithosols and regosols, with associated Calcisols and Sierozem-like soils.)

2d. Arid, distinct pattern of summer precipitation, high to very high day soil temperatures, coldest MMT within range 10-20°C, warmest MMT within range 20-30°C; sub-moderate weathering mainly effective in subsurface horizon, very weak leaching, moderate return of capillary salts through capillarity; drift regime moderate and organic regime weak: Desertic soils (Modal to Maximal Red Desert soils, Calcisols, and Sierozem-like soils with related lithosols and regosols, and with associated Solonchaks, etc.)

2e. Arid, no distinct seasonal pattern of precipitation, moderate day soil temperatures, coldest MMT within range 0-10°C, warmest MMT within range 10-20°C; very weak to minimal weathering throughout profile, very weak to weak leaching; moderate capillary return of soluble salts; drift regime locally very active; organic regime generally weak except for patches of local peat accumulation: Desertic soils (Gray, and Gray-brown Desertic soils, with related regosols and lithosols, and with associated Solonchaks, and Saline Organic soils, Half-bog soils, etc.)

2f. Arid, weak pattern of winter precipitation, moderate to high day soil temperatures, coldest MMT within range 0-10°C, warmest MMT within range 20-30°C; very weak weathering, very weak to weak leaching, moderate to strong capillary return of soluble salts; drift regime locally very active; organic regime weak: Desertic soils intergrading to Semi-desertic soils (Gray-brown and Brown Desertic soils, Calcisols, Sierozem-like soils, all with related regosols and lithosols, and with associated saline alluvial and colluvial soils, etc.)

3. <u>Desert region of highlands</u> (minimum elevation 3.000 m.)

3a. Arid, no distinct rhythm of precipitation, moderate day soil temperatures, coldest MMT within range 0-10°C, warmest month within range 10-20°C; very strong cold and dessicating winds and very low barometric pressures common: minimal weathering, minimal to very weak leaching, weak to moderate return of soluble salts by capillarity; drift regime generally active; organic regime weak and local: Desertic Altiplano soils (Minimal Gray Desert soils and related lithosols and regosols, with associated Recent Volcanic soils, Minimal Calcisols, Minimal Sierozem-like soils and derived colluvial and alluvial soils.)

3b. Arid, weakly defined pattern of summer precipitation, moderate day soil temperatures, coldest MMT within range 0-10°C, warmest MMT within range 10-20°C; frequent strong, cold and dessicating winds and low barometric pressures: minimal to very weak weathering, very weak leaching in part nullified by moderate capillary return of soluble salts; very active drift regime; organic regime weak and local: Desertic Altiplano soils (Gray, Brown and Reddish-brown Desertic soils and related lithosols and regosols, with associated Calcisols, Minimum Sierozem-like soils on more stable landforms, and with associated Recent Volcanic soils, and alkaline semi-bog soils.)

EXPLANATORY LEGEND TO FIG. 10

4. Semi-desert region of lowlands (maximum elevation 300 m.)

4a. Semi-arid, winter precipitation, moderate to high soil temperatures in summer, coldest MMT within range 10-20°C, warmest MMT within range 10-20°C; weak weathering of surface soils, sub-moderate weathering of subsoils, weak leaching in winter, in part counteracted by weak to moderate capillary return of soluble salts in late spring; drift regime weak to moderate; organic regime not better than moderate and locally weak: Semi-arid soils (Calcic Brown soils and related steepland soils and lithosols, with associated Grumosols, Rendzinas, and locally Minimal Non-Calcic Brown soils and their related steepland soils and lithosols).

4b. Semi-arid, winter precipitation, moderate day soil temperatures in summer, coldest MMT within range 0-10°C, warmest MMT within range 20-30°C; weak weathering throughout soil profile, weak winter leaching, in part counteracted by weak capillary return of soluble salts in summer; drift regime weak; organic regime moderate: Semi-arid soils (dominantly Non-Calcic Brown soils and their related steepland soils and lithosols, but with associated Calcic Brown soils, Grumosols, Rendzinas, and soils transitional to Red-brown Lateritic soils with their related steepland soils; also alluvial soils etc.)

4c. Semi-arid, winter precipitation, fairly high day soil temperatures in summer, coldest MMT within range 0-10°C, warmest MMT within range 20-30°C: weak to very weak weathering, weak leaching, weak to moderate return of soluble salts by capillarity; drift regime locally very active; organic regime mainly weak but locally moderate: Semi-arid soils (in part transitional to Semi-desertic soils and including Calcic Brown soils, Calcisols, Sierozem-like soils, Maximal Red Desert soils, Minimal Brown Forest soils etc., all with related lithosols and some steepland soils, and with derived alluvial and colluvial soils; locally some development of Recent Volcanic soils.)

4d. Semi-arid, no distinct seasonal rhythm of precipitation, warm to cool day soil temperatures in summer, coldest MMT within range 0-10°C, warmest MMT within range 10-20°C: weathering weak, leaching weak to moderate, capillary return of soluble salts weak; drift regime only locally moderate to strong; organic regime moderate, but locally strongly developed: Semi-arid soils (Minimal Chestnut soils, with Brown Semi-desertic soils, and with related regosols and lithosols; locally Half-bog and Bog soils).

4e. Semi-arid, summer precipitation, warm day soil temperatures in summer, coldest MMT within range 0-10°C, warmest MMT within range 20-30°C: weak to sub-moderate weathering, weak to moderate leaching, weak capillary return of soluble salts; drift regime locally active; organic regime moderate: Semi-arid soils (mainly Calcisols, Sierozem-like soils and related lithosols and regosols, and with associated Solonchaks, etc.)

4f. Semi-arid, summer precipitation, relatively hot day soil temperatures in summer, coldest MMT within range 10-20°C, warmest MMT 20-30°C: weak to moderate weathering, weak to moderate leaching, weak capillary return of soluble salts; drift regime locally active; organic regime moderate: Semi-arid soils (Reddish-brown and Brown desertic soils, Chestnut soils, etc., with related regosols and lithosols, and with associated Solonchaks, saline alluvial soils, hydromorphic soils etc.)

5. Semi-desert region of highlands (minimum elevation 3.000 m.)

Semi-arid, summer precipitation, cool day soil temperatures in summer, coldest MMT within range 0-10°C, warmest MMT within range 10-20°C; very cold, dessicating winds and low barometric pressures common: weak to very weak weathering, weak ranging to moderate weathering, weak capillary return of soluble salts in general, but rather strong capillary return of soluble salts in local peaty soil; drift regime locally very active; organic regime weak to moderate, locally strong where spring waters emerge at surface: Semi-arid altiplano soils (Brown desertic soils, Recent Volcanic soils, Minimal Paramo soils, grass-melanised very weakly weathered Acid-Brown Forest soils, etc., with related steepland and lithosolic soils; and with associated Organic soils.)

6. Semi-desert transitional to sub-humid region of lowlands (maximum elevation 2.000 m.)

6a. Semi-arid to sub-humid, winter precipitation but season has up to eight months without effective rainfall, warm summer day soil temperatures; very light forest cover, in part orchard savanna: weak to sub-moderate weathering, weak to sub-moderate leaching, very weak or no return of soluble salts through capillary action; drift regime moderate to weak; organic regime moderate: Transitional Semi-arid to Sub-humid soils (Minimal Brown Forest steepland soils on younger land surfaces with some Non-Calcic Brown soils; soils transitional between Non-Calcic Brown and Red-Brown Lateritic or Red-yellow Podzolic soils on older land surfaces; and associated Recent Alluvial soils, Recent Colluvial soils, Grumosols, etc.)

6b. Semi-arid to sub-humid, summer precipitation, warm to hot day soil temperatures in summer; light forest vegetation: moderate weathering, weak to moderate leaching, very weak or no capillary return of soluble salts; drift regime moderate to strong; organic regime weak to moderate: Transitional Semi-arid to Sub-humid soils (Brown Forest soils, Rubrozems, Cinnamon soils, etc., in part transitional to Red-brown lateritic soils and Red-yellow Podzolic soils, with related steepland soils, lithosols, regosols etc., and with associated Recent Alluvial soils, etc.)

6c. Semi-arid to sub-humid, no distinct pattern of seasonal precipitation and usually no months without some effective moisture, cool day soil temperatures in summer, soils frozen for several months in winter; moorland and tussock grassland vegetation: weathering weak to sub-moderate, leaching moderate, no return of soluble salts through capillarity, locally strong gleying; drift processes locally very strong; organic regime moderate to strong, local formation of peat bogs: Transitional Semi-arid to Sub-humid soils (Patagonian Prairie soils and soils transitional to Planosols mainly, with associated Half-bog and Organic soils).

7. Semi-desert transitional to sub-humid region of highlands (minimum elevation 3.000 m.)

7a. Semi-arid to sub-humid, winter precipitation but in part falling as snow, cool summer day soil temperatures; tussock grassland steppe with patches of light (Baccharis) scrub: weak to very weak weathering, weak to moderate leaching, minimal return of soluble salts through capillarity, locally weak to moderate gleying; drift regime moderately active; organic regime weak to moderate, but locally strong where spring waters emerge at surface of landscape and permit bog formation: Transitional Semi-arid to Sub-humid Altiplano soils (mainly Lithosols and Regosols related to Minimal Brown Forest soils, Brown Desertic soils, and grass-melanised Brown soils, with Recent Volcanic Ash soils and Minimal Paramo soils, and with associated local Organic soils and some saline Organic soils.)

7b. Semi-arid to sub-humid, summer precipitation falling as rain, but also with considerable cloud condensation at all times of the year, cool day soil temperatures in summer; dwarf forest (Chuquiragua oppositofolia): weak weathering, moderate to strong leaching, moderate gleying, no return of soluble salts through capillarity; drift regime moderate to weak; organic regime moderate to strong: Transitional Semi-arid to Sub-humid Altiplano soils (mainly steepland soils and lithosols related to Brown forest and Acid Brown Forest soils

8. Sub-humid region (lowlands and highlands)

8a. Sub-humid, winter precipitation but with 3 to 4 months without effective rainfall, warm summer day soil temperatures; medium forest cover: sub-moderate to moderate weathering, weak to moderate leaching, practically no return of soluble salts through capillarity; drift regime moderate to weak; organic regime moderate to strong: Sub-humid soils (Red-brown Lateritic soils and Red-yellow Podzolic soils on older land surfaces, with related steepland and colluvial soils; Brown Forest soils and related steepland soils and lithosols on younger land surfaces; and with occasional associated slight-to-moderately weathered allophanic (Trumao) soils and their derivative soils.)

8b. Sub-humid, winter precipitation but with much snow in winter and with only 2 to 3 months without effective precipitation, cool summer day soil temperatures; low forest (Nothofagus antarctica) grading to tussock grassland: weak to sub-moderate weathering, weak to moderate leaching, no capillary return of soluble salts, locally weak gleying; drift regime strong to very strong where natural forest destroyed, but only weak under natural conditions; organic regime moderate to strong: Sub-humid soils (Minimal Acid Brown Forest soils, Brown Forest soils, and related lithosols and steepland soils, and with associated weakly weathered allophanic (Trumao) soils, Half-bog and Organic soils, Recent Alluvial soils and Recent Colluvial soils).

8c. Sub-humid, summer precipitation, warm to hot summer day soil temperatures; medium forest cover in part: moderate to strong weathering, weak to sub-moderate leaching, no capillary return of soluble salts, locally weak gleying; drift regime moderate; organic regime moderate to weak: Sub-humid soils (Red-brown Lateritic soils, Red-yellow Podzolic soils, and related steepland soils, and with associated Hydromorphic soils.)

EXPLANATORY LEGEND TO FIG. 10

9. Humid region (lowlands and highlands)

9a. Humid, winter precipitation, usually 1 to 2 months when effective moisture is low, warm summer day soil temperatures; medium to heavy forest cover: moderate and moderate-to-strong weathering, moderate leaching, locally weak gleying; drift regime moderate; organic regime moderate to strong: Humid soils (Brown Forest soils and related steepland soils and lithosols on younger land surfaces; Red-brown Lateritic soils mainly on older land surfaces, together with related steepland soils; also associated sub-moderately to moderately weathered allophanic (Trumao soils) and their related hydromorphic soils (Nadi soils), Recent Alluvial soils, Colluvial soils and some Recent Volcanic ash soils)

9b. Humid, mainly winter precipitation but effective moisture all through the year, warm to cool summer day soil temperatures; heavy forest cover except on Post-Glacial volcanic ash soils where parkland formation present: moderate-to-strong and strong weathering, moderate-to-strong leaching, locally moderate gleying; drift regime weak (apart from periodic additions of fresh volcanic ash); organic regime strong to very strong: Humid soils (Acid Brown forest soils and related steepland soils and lithosols on younger land surfaces free of volcanic ash mantle; Red-brown Lateritic soils on older land surfaces free of ash mantle or formed from as emplaced during last pre-glacial period or earlier; moderate to strongly weathered allophanic (Trumao) soils and related hydromorphic soils (Nadi soils) elsewhere; also some Gley soils and Organic soils).

10. Super-humid region (lowlands and highlands)

10a. Super-humid, mainly winter precipitation but no clear seasonal pattern of rainfall distribution, cool summer day soil temperatures; heavy rainforest cover: moderate and strong weathering, strong to very strong leaching, locally conditioned by acid humus emplaced by forest, fairly general moderate-to-strong gleying; drift regime weak; organic regime very strong: Super-humid soils (mainly Acid Brown Forest steepland and lithosolic soils, locally podzolised; Rankers; strongly leached, weathered allophanic (Trumao) soils and related Hydromorphic soils; Organic soils, etc.)

10b. Super-humid, no distinct pattern of seasonal precipitation, all months equally wet, moderate snow accumulation in winter, cool to cold day soil temperatures in summer; heavy rainforest (Nothofagus) cover: weak weathering, very strong leaching, moderate to strong gleying; drift regime moderate to weak; organic regime very strong: Super-humid soils (mainly Podzols and Gley-podzols on steep slopes; Rankers; with associated Gley soils and Organic soils.)

10c. Super-humid, no clear seasonal rhythm of precipitation, all months equally wet, strong salt-laden westerly winds, cool summer day soil temperatures; Magellanic moorland vegetation and Nothofagus forest: weak weathering, very strong leaching strongly conditioned by acid plant residues accumulating on soil surface, generally strong gleying; drift regime weak to moderate; organic regime very strong: Super-humid soils (Gley-podzols, Organic soils, Podzols and Rankers common, often extending onto steep slopes.)

EXPLANATORY LEGEND TO FIG. 10

10d. Super-humid, no clear seasonal pattern of precipitation but heavy snowfall in autumm, winter and spring months, cold to very cold day soil temperatures in summer; tussock grassland, stunted scrub and sub-alpine herbfield plant formations: very weak weathering, strong leaching, strong gleying; active drift regime (solifluction, etc.); moderate to strong organic regime: Super-humid subalpine soils (Gleyed Subalpine soils, Lithosols, Regosols, Rankers, and Organic soils.)

TABLE 1: GENERAL PLAN OF FARM DEVELOPMENT

	Previous Production	1st. year	2nd. year	3rd. year	4th. year	5th. year
a) 400 Hectares of available clean land						
Wheat (has)	40	100	65	65	65	65
Improved pasture (has)	-	-	100	165	230	295
Closed for grass seed production (has)	-	40	40	40	40	40
Unimproved grassland (has)	360	260	195	130	65	-
b) 500 Hectares of land at present not cleared						
Wheat (has)	-	60	60	60	60	60
Improved pasture (has)	-	-	60	120	180	240
Closed for grass seed production (has)	-	-	60	60	60	60
Unimproved grassland (has)	500	440	320	260	200	140
c) 3600 Hectares of hilly land						
Improved grassland (has)	-	-	30	50	80	100
d) Growth of flock						
Rams	8	30	29	41	53	70
Ewes	210	1000	970	1382	1768	2325
2-tooth breeding ewes	80	450	877	1049	1406	1875
e) Summary						
Annual area sown in wheat (has)	40	160	125	125	125	125
Pasture production from improved grassland (has)	-	-	190	335	490	635
Area closed for grass seed production (has)	-	40	100	100	100	100
Number of steers fattened annually	80	100	150	230	350	500
Number of hoggets sold ann.	103	450	437	622	796	1046
Production of wool (kgs)	550	3090	4320	5700	7293	9522
Production of ensilage (tons)	-	100	150	230	350	500
Production of hay (tons)	-	35	50	75	120	170
Grazing requirements in sheep/month units	-	17160	20613	27552	35828	47011
Grazing available in sheep/ month units	-	12100	20175	37025	48275	59525

TABLE 2: OUTLAY AND FINANCING OF FARM DEVELOPMENT

	Outlay E°	Credit (years)	Repayment of Credit 1st. year	2nd. year	3rd. year	4th. year	5th. year
1) Fencing: (10 km. of fencing at E°250 per Km)	2.500	4	10%	30%	30%	30%	–
Amortization			250	750	750	750	
Interest at 10%			250	225	150	75	
2) Clearing of land (90 has to be cleared at E°100/ha)	9.000	5	0	20%	20%	20%	40%
Amortization			–	1.800	1.800	1.800	3.600
Interest at 10%			900	900	720	540	360
3) Purchase of ewes (1000 head at E° 18 each)	18.000	2	0	100%	–	–	–
Amortization			–	18.000	–	–	–
Interest at 10%			1.800	1.800	–	–	–
4) Purchase of rams (30 rams at E° 100 each)	3.000	2	0	100%	–	–	–
Amortization			–	3.000	–	–	–
Interest at 10%			300	300			
5) Pasture seed (seed for 200 has. at E° 25 per ha)	5.000	3	0	30%	70%	–	–
Amortization			–	1.500	3.500	–	–
Interest at 10%			500	500	350	–	–
6) Fertilizer for pastures (fertilizer for 200 has at E° 30 per ha)	6.000	3	0	30%	70%	– –	– –
Amortization			–	1.800	4.200	–	–
Interest at 10%			600	600	420		
7) Equipment and machinery (tractor, cultivator, harrows, sower, etc.) Total cost E° 18,000	18.000	3	30%	30%	40%	–	–
Amortization			5.400	5.400	7.200	–	–
Interest at 10%			1.800	1.260	720	–	–
TOTAL E°	63.500		11.800	37.835	19.810	3.165	3.960

(Amortization and Interest – E° 76.570 – E° 63.500 = E° 13.070 = 20.47%)

TABLE 3a: SUMMARY OF POTENTIAL RETURNS DURING FIRST TWO YEARS

Production	Gross Income	Expenses	Returns
1st. Year			
Wheat	E° 32.000	E° 16.000	E° 16.000
Sale of sheep	6.750	1.012	5.738
Wool production	6.180	927	5.253
Sale of fat cattle	19.800	15.465	4.335
	E° 64.630	E° 33.404	E° 31.226
2nd. Year			
Wheat	E° 25.000	E° 12.500	E° 12.500
Sale of sheep	6.555	983	5.572
Wool production	8.640	1.296	7.344
Sale of fat cattle	29.600	23.180	6.420
Grass seed production	24.000	8.000	16.000
	E° 93.795	E° 45.959	E° 47.836

TABLE 3b: SUMMARY OF POTENTIAL PROFITS DURING FIRST TWO YEARS

	1st. year	2nd. year
Returns from farm	E°31.226	E°47.836
Repayment of loans	11.800	37.835
Profit	+ 19.426	+ 10.001